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REACH AND PRESENCE

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Disclaimer

2025 is a study designed to comply with a directive from the chief of staff of the Air Force to examine the concepts, capabilities, and technologies the United States will require to remain the dominant air and space force in the future. Presented on 17 June 1996, this report was produced in the Department of Defense school environment of academic freedom and in the interest of advancing concepts related to national defense. The views expressed in this report are those of the authors and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the United States government.

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Preface

Aptitude for war is aptitude for movement.

—Napoléon

Knowing what is transpiring in the world is one thing. Doing something about it is quite another. In many cases, being able to arrive at a particular place at a particular time with particular capabilities is part of the policy solution. Doing so from a distance in a timely fashion is part of what the USAF is all about. Furthermore, deploying and sustaining a presence of various kinds—aerial reconnaissance, humanitarian relief, peacekeeping, combat capability, space-based surveillance—are USAF capabilities critical to making use of knowledge, updating it, and maintaining its flow from a variety of on-site assets. Arriving and remaining on-site for an indefinite time under hostile conditions is also part of the mission of global reach—of establishing presence, which can be either virtual or actual in 2025.

Global reach—presence—is the USAF's ability to utilize its responsiveness to deploy nearly anywhere in the world, on relatively short notice, in a matter of hours rather than the days or weeks that surface forces may require. Doing so routinely, on a daily basis, is now part of the USAF mission. That capability will be strenuously tested in the twenty-first century and will demand more creative technological solutions in order to continue in the world of 2025.

(Please note that appendix A contains a list of all the papers in the ***2025*** study, arranged by volume for ready reference. Also, appendix B contains a list of all the people—military and civilian, warriors and scientists, educators and operators, leaders and supporters—who contributed to the ***2025*** project.)

Logistics in 2025: *Consider It Done!*

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Executive Summary

Accessibility replaces anxiety in 2025 logistics. Confident that logistics systems will generate what they need when they need it, commanders of aerospace forces in the year 2025 contemplate strategy and devote their energy to the battle. The overall goal of this logistics thinking team was to ensure that commanders of 2025 retain visibility and control of the resources required to support national security objectives of the United States.

This paper proposes a "system of systems"[1] to provide a commander total asset visibility and seamless integration from cradle to grave for all major systems and their components. Advanced logic built into these systems streamlines the four core logistics processes discussed.

Acquisition: Acquisition reform and protected access to automated systems allows machines to procure consumable and durable goods. Human intervention by empowered employees is required only when defined parameters are exceeded. Critical concepts and subsystems of this system are communications, artificial intelligence, miniaturization, and virtual reality.

Materiel Management: Increased reliability and maintainability, purchases directly from the manufacturer, and on-the-spot manufacturing reduces materiel management requirements. Advanced miniaturization, communication systems, and computer aided design and manufacturing, plus recycling concepts deliver requirements when needed.

Transportation: Airlift is the major constraint in meeting current deployment objectives. A reduced footprint eases the airlift requirement. Efficient engines requiring less fuel and miniaturization yield increased lift capacity. Undersea and spaceborne prepositioning and linked communication systems facilitate expeditious transfer of goods.

Maintenance: An aging fleet challenges 2025 maintenance personnel. Improved reliability and maintainability reduce the overall maintenance requirement. Modular construction, interoperable parts, lean logistics, and improved diagnostic and visual repair instructions improve the repair process. On-the-spot manufacturing increases maintenance flexibility. Improved materials, communication systems, computer aided design and manufacturing techniques, virtual reality, and miniaturization concepts are critical to streamlined maintenance in 2025.

Alternatives adopted by today's leadership in acquisition, materiel management, transportation, and maintenance ensure that support is on target and that the 2025 commander is in charge of the mission.

Note

1. Lt Gen Jay W. Kelley, "Brilliant Warrior" unpublished paper (Air University, Maxwell AFB, Ala., 1996), 5.

Chapter 1

Introduction

Logistics has been a concern for military commanders since the beginning of time. Any organization, be it military or civilian, consumes resources and requires replenishment to accomplish its mission. Since merely wishing for supplies and support does not work, a formal logistics infrastructure is necessary to ensure support for any mission.

In 2025, as today, aerospace commanders may be asked to perform missions ranging from humanitarian support to total war. This paper proposes a logistics structure that includes a powerful new system capable of seamlessly integrating all logistics functions. This system would provide total asset visibility throughout the logistics process by linking all functions under one automated, "intelligent" system.

A highly sophisticated system that incorporates artificial intelligence, connectivity of automated systems, and hardened communications capabilities, it would introduce a logistics "system of systems" known as the battlespace responsive agile integrated network (BRAIN). This system would enable the logistician to efficiently and effectively manage assets to support the military commander.

This study discusses new technologies to shorten the logistics tail and reduce its footprint. By using highly reliable and miniaturized parts, we could reduce the amount of materiel that must be warehoused to support tomorrow's force. Additionally, this paper recommends employment of manufacturing techniques using lasers and advanced materials to manufacture on the spot at maintenance facilities and in the battlespace. Such repair reduces the amount of material to be transported. In the future, we expect self-assessing "smart parts" that automatically interface with the system to replenish themselves. Such replenishment would reduce the time and efforts required of maintenance and supply personnel.

In an increasingly austere environment, it is imperative that we get the most bang for every buck. BRAIN would enable the logistician to assure the commander to "consider it done" no matter how large or small the requirement may be.

Chapter 2

Required Capabilities

Regardless of events in the future, the key to air and space logistics capability is to transition from a primarily push (to the user) to a predominantly pull (at the user's demand) system. The balance between maintaining mission-essential materials for aerospace commanders and the high cost of storing excess material will not change. The logistics mission of getting the *right thing* to the *right place* at the *right time* and the *right cost* is a bulwark of military effectiveness.

Pull logistics, pressured by a cost-conscious public, will move depot operations to significantly smaller, decentralized facilities. Once instituted, pull logistics will require commanders to make a major paradigm shift. They will need to trust the newer system and decrease their reliance on stockpiling noncritical items.

Operators with pocket computers will load part specifications into computer aided design (CAD) software; miniature, portable machines with computer aided manufacturing (CAM) capability will allow operators to manufacture items at or near the point of need.[1] Microscopic, multipurpose snap-out chips and diminutive motherboards can be carried in wallet-sized pouches for on-site repairs. In addition to CAD capability, virtual reality systems will provide pictorial, oral, and written installation and repair instructions.

Immediate communication links with industry worldwide combined with on-line credit will become standard operating procedure. As global markets develop, the interests of Congress will shift to faster, better, and cheaper methods of promoting competition. Out of necessity, the Federal Acquisition Regulation (FAR) will be streamlined. Rules that place acquisition authority in the hands of a few will be changed to empower a multitude of users to acquire necessities with minimum bureaucracy. Operators will be empowered to deal directly with manufacturers for items that are neither in stock nor adaptable to on-the-spot manufacturing. Factory-direct orders will substantially decrease the requirement for storage and distribution facilities and quick access to goods will allow a significantly reduced inventory that is collocated with the operator. The commander will have access to all information and will be able to request information on materiel availability or status in any form.

One of today's major problems is the lack of interoperability between computer systems. In 2025, multiple aerospace computer systems must interface with each other. Additionally, it is critical that those network links are extended to other services, foreign military units, and industry throughout the world.

Demands for efficient uses of taxpayer funds will result in continuing cost comparison efforts. The historic trend toward increased contractor awards will not change. Therefore, much of the remaining maintenance, repair, transportation, and storage facilities will have been privatized. There is much dissent throughout the system regarding the balance between the need for maintaining an adequate industrial base and the necessity for ensuring sufficient organic capability for mobilization.

As decentralization becomes reality, the target sets change. No longer are logistics support facilities (organic or private) centers of gravity—they are small and dispersed. No longer are communication centers a center of gravity—each person has a personal small pocket computer/communication tool. No longer are communication transmitters a center of gravity—multiple

communication transmitters provide alternative links in the event any one link or group of links is incapacitated. Although we have reduced our centers of gravity, in 2025, everything is a target.

"We already know that older forms of warfare do not entirely disappear when newer ones arise."[2] This also can be said of technological advances. As we reach to the future and find solutions to old problems, those problems will not go away entirely. The old issues will become increasingly blurred with new problems.

Since the current joint forces definition of logistics is, "the process of planning and executing the movement and sustainment of operating forces in the execution of a military strategy and operations,"[3] that definition will not change in 2025.

To that end, we have identified four core capabilities: *acquisition, materiel management, transportation* and *maintenance.* The relationship of these core capabilities to the logistics goal, mission, and principles is illustrated in figure 2-1.

Figure 2-1. Logistics Goal, Mission, Core Competencies, and Principles

Although traditionally considered part of logistics, we have excluded base operating support activities and research and development. We also do not discuss the method of delivery, air, sea, ground, etc.). We assume an adequate combination of private and in-house delivery sources. We also assume that delivery systems and delivery ports will be adequately protected to ensure merchandise delivery in the year 2025. Furthermore, we do not address communications systems. The scope of that subject is far too complex for this paper. Therefore, we assume that communication systems will be hardened and that alternate sources of delivery will be available. For example, if the BRAIN relies on satellites for communication, we assume that, should a satellite become inoperable, another satellite or a ground communication system will be available to ensure uninterrupted data transmission.

We are aware of the potential for logistics to become a joint (multiservice) agency, a combined (multinational) organization, or one owned and operated entirely by private industry. Whatever happens, the concepts we discuss could easily be adapted by any or all of these organizations.

Notes

1. Dr Craig M. Brandt et al., "Logistics 2025: Changing Environments, Technologies, and Processes" (Maxwell AFB, Ala.: Draft paper for Air War College ***2025*** study, 1996), 28–29.
2. Alvin and Heidi Toffler, *War and Anti-War* (New York: Warner Books, Inc., 1995), 97.
3. Joint Publication (JP) 4-0, *Logistics*, 27 January 1995, I-1.

Chapter 3

System Description

All who study the government acquisition process agree acquisition reform is necessary. The acquisition system is being suffocated by the weight of the regulations designed to protect it. The reaction to several incidents of reported price gouging and cost overruns in the 1980s led to excessive regulatory oversight and control.

Acquisition

In the 1990s, Congress began adjusting the proverbial pendulum by enacting comprehensive legislation to streamline the military acquisition process. Leading the storm of reformation, Darlene Druyan, assistant secretary of the Air Force (acquisition), sparked change in the acquisition community when she issued eight lightning bolt initiatives on 31 May 1995. The initiatives called for bold and sweeping changes in how the Air Force runs its acquisition program.

While these "lightning bolts" shake the very earth on which the acquisition community stands, Druyan acknowledges this is just the *first step* in a series of required reforms. "People in the work force really want to do the right thing," she says, "we just need to give them guidance and council [sic]—we need to let them know it's OK to remake their own roles in our acquisition system."[1] It is essential that the government further automate the acquisition process and empower the military service user to deal directly with the supplier more frequently. The inflexible system currently in place is bureaucratic, redundant, and unresponsive to the needs of those charged with defending the nation. Development cycle comparison provides a good example.

Figure 3-1 shows that the time required to purchase major weapon systems ranges from four to 15 years.

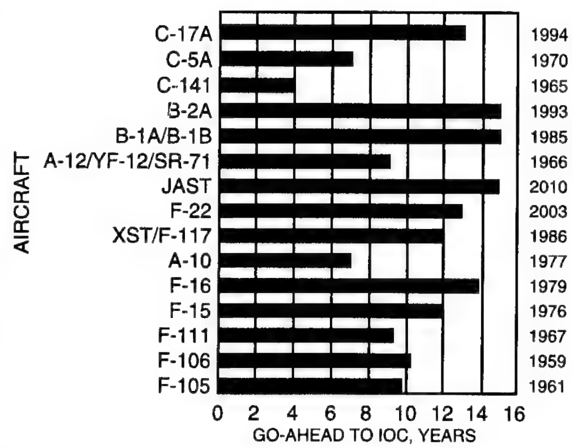

Figure 3-1. USAF Aircraft Development Cycles[2]

With technology development doubling every year, acquisition personnel often end up purchasing outdated equipment before it leaves the drawing board. The cost of modifications made between the time of approval and receipt of the product creates delay, contributes to user anxiety, and costs millions of dollars.

On a much smaller and more understandable scale, the time required from "identification of need" to "satisfaction" is keeping us a generation behind. For example, ordering a software package can take five to seven years. This is inefficient and puts our government in a position of always being several steps behind industry. As technology progresses, this unacceptable lead time will result in a quantum governmental technology lag. To survive, the aerospace forces must assume a posture of industrial fusion rather than lagging separation. If the United States government does not get in step and stay in step with industry, countries who assume a progressive posture will quickly outpace, outperform, and, if so motivated, decisively defeat the United States military forces. It is

critical that the United States armed forces be seamlessly integrated with industry.

The ideal way to expedite the acquisition system and achieve seamlessness is to empower the user and provide safeguards for those individuals with an automated system. The systems proposed herein would have sufficient safeguards to ensure that only the proper user has access to the system and has not exceeded procurement authority. Purchases not meeting the requester's requirements would not be automatically dismissed, but would flow to a higher automated or human review.

To avoid excessive training costs, the automated system must be simple and easy to use. However, the software would by necessity be complex. The "user/buyer" will not necessarily be a human being, it could be an inanimate device such as a maintenance microchip embedded in a weapon system or part. The following section describes how BRAIN, our concept of a fully automated system, would streamline the acquisition process.

Microchip Purchases (Existing Stock)

The concept of a chip initiating a purchase to replenish stock presents a revolutionary opportunity for enhancing the acquisition process. "Machines need to talk easily to one another in order to better serve people."[3] For example, a microchip embedded in a hydraulic pump on an aircraft determines that the pump is eroding and will require replacement within five weeks. This microchip would transmit through a communication system, such as a satellite, the need to replace the pump. The requirement would enter "Otto" Auditor, the gatekeeper of the system. Otto would automatically query other systems to determine if a bona fide purchase requirement exists.

First, Otto contacts "Red E. Ness." Red addresses the requirement from a national strategy perspective. Is the jet on which this pump is located going to be in the inventory when the replacement part is required? What is the importance of this jet in the prioritization list? If the requirement passes the need verification, Red sends Otto a message to proceed. Otto simultaneously contacts the other resource systems, "Budge-It," "Man-Per," and "Add-R-Quit Space."

Budge-It assesses the unit's budget and determines funding availability at the time of need. This system further makes decisions and performs calculations associated with the purchase. For example, Budge-It may determine the unit does not have the appropriate category of funds available to complete a transaction. It may then reallocate money from one category to another to allow the purchase.

Man-Per addresses the need for someone to perform the work. Are the right skills available in the appropriate place at the time the pump is scheduled for replacement? Man-Per contacts all associated support systems to ensure that medical support is available if someone is hurt while replacing the pump, that a fire station can support an emergency, and so forth.

Add-R-Quit Space checks to see if the appropriate repair facility is available at the right location when the pump needs replacement. If all systems are go, Otto contacts Virt-U-Log who scans the globe to determine if the part is currently available. If this is a high priority aircraft, a pump may be diverted from another repair site to replace this pump. Is the system at the right place at the appropriate time? If not, the request would return to Otto Auditor. Otto would perform a series of "decisions." For example, is this a normal replacement? If not, the system might "decide" to refer the request to a human maintenance checker who would determine whether this required further investigation. If not, the maintenance checker would electronically coordinate and refer the request back to Otto.

Once the request has been validated, the Budge-It system would then allocate funds for the purchase. Having coordinated electronically, Budge-It would send the request back to Otto. Otto would then execute many decisions to ensure the full

coordination of all concerned functions, processes, or departments. These decisions are processed in milliseconds, with corrections and reviews made quickly. Human interface would be required only when built-in systems signaled problems requiring intervention.[4] The end point for complications not remedied automatically would always be a human. This final human intervention would ensure that nonstandard requests would not be tossed into a computer trash can. Figure 3-2 graphically depicts the interactions of the future logistics systems.

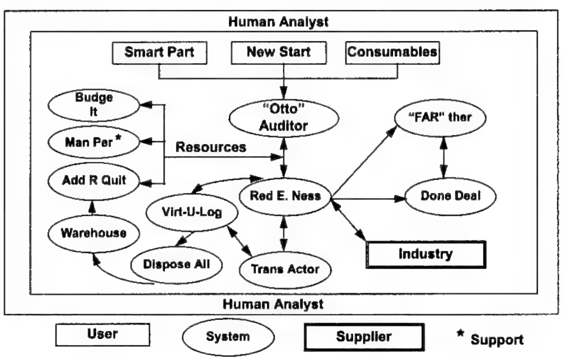

Figure 3-2. Battlespace Responsive Agile Integrated Network (BRAIN)

Upon completing its audit process, Otto would interface with a final "Smart Parts" system. Smart Parts would determine if the requested part fulfills the need. For example, it will determine if the pump fits the specific C-17 that ordered it. After ensuring that the part to be ordered meets the requirements, the system will identify a supplier and determine if that supplier proposes the best value. After Smart Parts identifies an appropriate vendor and determines whether that vendor is able to provide the part at the right time, it orders the part.

Smart Parts would then interface with "Trans-Actor." Trans-Actor would arrange to have the part delivered to the right place at the right time. It would track the item from time of receipt to time of delivery. Depending on part criticality, the details of tracking may vary. For example, for highly critical items, the system would know from minute to minute exactly where the item was. However, for less important items, Trans-Actor would provide visibility only when the part changed hands. Delivery may either be by organic or private sources. It would "correspond" with the aircraft to ensure that it was going to the designated repair site on the scheduled day of repair. In the event the repair site or schedule changes, Trans-Actor will reroute the part to a different location or alter the delivery date accordingly.

The casual observer can quickly see that the key to success is automated, integrated systems. Due to the global nature of transactions tomorrow, the systems will require international integration. Provisions for helping less automated, yet otherwise qualified, suppliers are necessary for the overall success of the bidding process. An on-line home page, accessible to anyone, would be required to ensure that small businesses and small countries with high-quality, low-cost items could compete in the system.

Human-Generated Purchases

Authority verification for microchip purchases could be embedded in the microchip. However, the verification for human-generated purchases would be more complex and would require technology which is not currently used in personal computers. Computers could be equipped with biologically sensitive computer eyeball "printing," a process that is similar to fingerprinting. Humans have distinctive, one-of-a-kind patterns on their eyeballs, just as they have unique fingerprints. Computers with eyeball printing capability could verify that the purchaser is who he claims to be. A "face recognition" verification system would provide a second check when a dual check system is required. This face recognition system allows the computer to read the face and chemical makeup of individuals as they walk in the room.

Once verification is complete, the user would prepare the order. This information would be transmitted to Otto to ensure that, just as with the microchip, the individual is a qualified person who has the authority to transact this purchase request.

New Acquisition Purchases

The concept of integrating all functions is as important as the process of buying new weapon systems. As the acquisition process evolves from oversight to insight, a mental shift to define what is required rather than how to perform must occur. No longer will hordes of government engineers review and revise contractor plans. The scenario that follows demonstrates the potential magnitude of the costs associated with today's oversight. A notional systems program office could directly employ an average of 165 employees over a 15-year period. Using an average of $34,000 per employee, the salary costs over the 15-year period would exceed $85M ($5.6M per year). This figure does not include employee benefits, support personnel, cost of travel, redesign, supplies, or equipment.

How, then can this be done? Rather than competing for project contracts every four or five years, contractors would have full authority to manufacture the item and maintain the system from cradle to grave. Rewards for timeliness, high performance, reliability, and maintainability would be built into the contract. Likewise, stiff sanctions involving suitability for future contracts and monetary penalties would be imposed on those who fail to perform.

The bid solicitation process would be computerized. Before bids are released, all organizations concerned, such as maintenance, budget, manpower, personnel, and supply, would simultaneously review the computer generated bid. Coordination would be required within hours or days rather than weeks and months. Much of the review would take place electronically. Again, human interface is only required if problems arise that are beyond the problem-solving capability of the computer reviewer's artificial intelligence.

Submission of contractor bids would be required within days. For the less sophisticated bidder, training programs would be available. All information and specifications would be available electronically. Forms for bid submission would allow bidders to simply and easily fill in the blanks. Standardized bid forms would speed up evaluation after bid submission. BRAIN would recognize anomalies and they would be tagged for human intervention. Calculations will be automatically performed. The simplicity of the new bid system would streamline the workload and might increase competition.

Materiel Management

A primary consideration in the logistics system of the future will be that of increased reliability of replacement parts. Improvements in reliability, maintainability, and deployability are indeed challenges to traditional logistics concepts.[5] This dynamic is true regardless of the future threats that aerospace forces will face in the next 30 years. A magnitude of increased reliability would result in a decreased need for parts in inventory, storage costs, time, and effort expended in testing for defective components and replacing critical parts. An example of this is cited in *New World Vistas:*

> When a turbine disk is degraded by fatigue in the bore of the component, the whole disk is replaced at a cost of $40K. Considerable savings might be affected by the use of new materials with improved properties and production methods that are more reliable. Furthermore, changes in design to permit replacement of only the degraded part of the component may also lead to significant decreases in costs. In replacing F-16 damaged fuselage frames, a new alloy, Al-Li alloys, will be used. These new alloys will be more reliable than the older alloys used originally. Also, these new alloys have lower densities and hence, result in weight savings, which is an additional benefit.[6]

Greater reliability of equipment and parts would also result in greater ease of monitoring safety levels of stock.

Just-in-Time Logistics

The core competency of materiel management includes the functions of distribution, movement, storage, preservation, and disposal.[7] Just-in-time logistics capitalizes on the distribution and movement functions by getting the right things to the end-user exactly when needed or as close to that time as possible. The warehousing function is thereby greatly reduced and the process is made more economical.

The first technology to address the logistics processes relevant in 2025 is that of a just-in-time logistics system using a worldwide, satellite-based communication system. The use of broad-band frequency sharing on existing satellite constellations would make this feasible by eliminating the need for dedicated orbiting platforms. This concept is not new. The US currently leases commercial satellites to augment existing frequency capabilities.[8]

In 2025, critical weapon systems and their supporting components will communicate with a worldwide logistics system through the use of small integrated circuits.[9] Transportation, rather than storage, will become paramount in delivering equipment and supplies on time to the correct end-user.[10] Taken individually, the capability of each chip may not be great on a relative basis, but collectively these individual chips and the items they are attached to can be monitored for usable shelf life, current stock status, and location. Just-in-time logistics, coupled with the technology of parts that "communicate" with the logistics system, will significantly reduce the quantities of stock sitting on shelves awaiting issue.

These "smart packages" or replacement parts would "talk" to a new series of satellites and their corresponding ground communication collection stations. This constellation of satellites would be deployed in groups of four: a prime collector/communicator, a transmission-only slave, a constellation backup, and a countermeasures/self-defense platform. Satellite communications must be enhanced to support increases in bandwidth demands. This type of satellite-based logistics system would require more bandwidth sharing. This, along with other battlespace data requirements, will place greater demands upon the communications capability of future satellite systems. However, according to *New World Vistas*,

> current efforts in fiber networks and laser communications are examples of areas where spacecraft and ground operations will benefit from commercial advances. Data compression techniques provide virtual bandwidth expansion and help minimize uplink requirements. Also, protocol advances such as the demand assigned multiple access (DAMA) will further enhance the capability of communication networks supporting the space mission.[11]

Perhaps the satellite bandwidth sharing mentioned above will be integrated with the 2025 combat support thinking team's concept of a virtual integrated planning and execution resource system (VIPERS). This system allows the commander to quickly view and assess the battlespace and, therefore, plan the theater campaign with much more confidence. A fundamental component of VIPERS deals with responding to the commander's need for the proper types and amounts of supplies and equipment needed to execute the mission. VIPERS relies on a constellation of advanced communication satellites.[12] Corresponding ground stations needed to interpret this data would exist within theater at the headquarters for each service as well as at the unified commander in chief (CINC) command level.

An example of how this system would work is illustrated by a weapons platform discharging a precision guided munition. When the weapon is discharged from the platform, a computer chip on the weapon automatically transmits a signal to BRAIN via satellite. Thus, this munition reports itself as employed and no longer available for use, and reports that a replacement may be needed in-theater. If the decision is to replace the asset and there are none on the shelf, the requirement will be referred to the acquisition process within BRAIN. If the

unit has no funding or the system is unable to complete the transaction for other reasons, the request would be referred to a human analyst (fig. 3-2) for further consideration.

This concept can also be applied to various other consumable supplies to include foodstuffs, personnel-related items such as clothing, and degradable medical supplies. This type of robust capability will allow for more rapid response and logistics cycle times and, thus, better support for the combatant commander.

Smart Package Technology/Trans-Actor

A derivation of this concept can be applied as a "smart package." Large containers or large parts such as aircraft engines could also be equipped with chips that sense the package's or part's environment or status.[13] When the materiel in the container needs to be moved to the theater of operations, the Trans-Actor subsystem of BRAIN programs the chip not only for its correct final destination but also the optimal path for reaching the field and perhaps even the use to which the items are intended.

When the package or part deviates from its known path or use, or when there is an unacceptable change in the package's contents, it would communicate this change to BRAIN through the above-mentioned satellite network. Before releasing its contents, this smart package would demand authentication from the customer and also tell the customer the status of its contents and availability for use. Likewise this data would be downlinked to the satellite network so that logistics headquarters would receive notice of the package's arrival.

An added dimension of Trans-Actor is the ability to have parts delivered to the right place at the right time. Trans-Actor would "correspond" with the delivering vehicle to ensure that it was going to the designated resupply or repair site at exactly the predesignated time. If a delivery conflict developed, this system would automatically reroute the part to a different location or alter the delivery date accordingly.

Building Up the Foundation

The developing technologies for truly just-in-time logistics are here now. Our current system of GPS satellites (fig. 3-3), along with our current mobile satellite tracking stations would have to be upgraded to the next generation of applicable software.

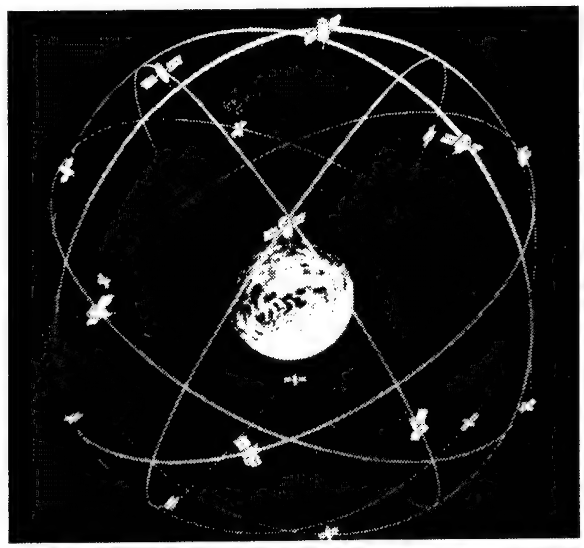

Figure 3-3. Global Positioning System Constellation

A system of "radio tags" that communicate with each other and to mobile and fixed terminals is being developed by a California company. These labels could be attached to containers and/or large pieces of equipment and instantly become inexpensive radio beacons. These beacons would continually transmit the simple tag number to a "smarter" tag actually within the container or piece of equipment. This internal tag would have the manifest of the contents and directions for its shipping and disposition. These tags could then be attached to a variety of sensors to measure temperature, tampering, or leaks.

This system would be susceptible to certain countermeasures. The GPS receiver systems could be jammed or fed false data.

Additionally, the receivers could theoretically be subject to "info wars" techniques such as the introduction of viruses into their software. The system would also be vulnerable if the enemy were able to decrypt the downlinked data at any point in the transmission process. Of course, direct attack of the satellite constellations by air-launched missiles or ground-based systems may be possible. Possible counter countermeasures to such a system involves hardening communication systems and making them more redundant. If one system fails, an alternate satellite constellation is activated to ensure seamless transmission of data.

This proposed just-in-time logistics system has an inherent advantage of being equally useful in both wartime and peace. The satellites are always in orbit and functional the vast majority of the time.

Each theater of operation would, in theory, have a logistics center along with the supporting satellite ground station. Logistics centers and the supporting ground satellite centers could be CONUS-based or afloat in prepositioned areas. The potential exists to use this logistics system on a daily basis to support global business. Our military would lease or use parts of the system only as needed by our national command authorities. In the future such sharing and "recycling" of scarce, expensive resources will help create a more seamless military-industrial complex relationship.[14] This is vital, considering how unbearably expensive logistics systems have become.

Just-in-time logistics systems will have varying degrees of vulnerability in any level of conflict. To reduce this vulnerability and provide some measure of redundancy, the concept of assured delivery must be introduced. Assured delivery simply acts as a redundant subsystem of just-in-time to guarantee that emergency stockpiles of critical items are always available to the war-fighting CINC. These stockpiles are at critical secure points that could be used should the overall just-in-time system be interdicted or interrupted. Undersea prepositioning, as described later in this paper, is an example of one such protected critical point. While not totally invulnerable, assured delivery gives the CINC some measure of logistical insurance.[15]

Another potential problem with just-in-time logistics arises from the reliance on just one supplier or subcontractor to manufacture a needed part or subcomponent. A recent example of this happening was the March 1996 strike by a General Motors brake assembly plant in Dayton, Ohio. The shutdown idled a total of almost 167,000 workers and halted production in 26 of General Motors' 29 North American plants.[16] To counter these types of production shutdowns, redundancy should be introduced into the manufacturing process by providing for multiple suppliers of key components whenever possible.

Reverse Logistics

The idea of environmentally correct warfare will undoubtedly be important in the future. One of the necessary components of materiel management will involve the proper disposal and/or recycling of a large number of the items used in the battlespace of the future. The materials used by the aerospace power of the future may be significantly more toxic than those used today. If so, society will demand their proper disposal. Sherri Wasserman Goodman, under secretary for environmental security, stated to Congress in 1994 that, "at first notion a green weapon system may seem absurd, but in reality it is not. Those systems spend most of their lives in a peacetime role and often remain in the inventory for 30 years or more. During that time maintenance and refurbishment performed by contract and at our industrial depots use large quantities of hazardous materials and generate large quantities of waste."[17] This trend will certainly continue. The materials manager in the year 2025 must learn from the example of industry and also concurrently develop environmentally benign methods to dispose of outdated weapon systems and their infrastructures.

A maturing concept that will help in the reverse logistics process of the future is the life-cycle assessment (LCA). This concept displays an acceptance by manufacturers of their willingness to share responsibility for the environmental burden of a product from initial design to final disposal.[18]

Life-cycle assessment goes beyond mere superficial environmental improvements targeted at the disposal phase. This process is a snapshot in time of total system inputs and outputs involved with a weapon system, process, or related activity. Life-cycle assessment is expensive but is thought to be effective. It is composed of three separate but interrelated components: life-cycle inventory, life-cycle impact analysis, and life-cycle improvement analysis.[19]

The "pollutant universe" that LCA will attempt to deal with is shown below in figure 3-4.

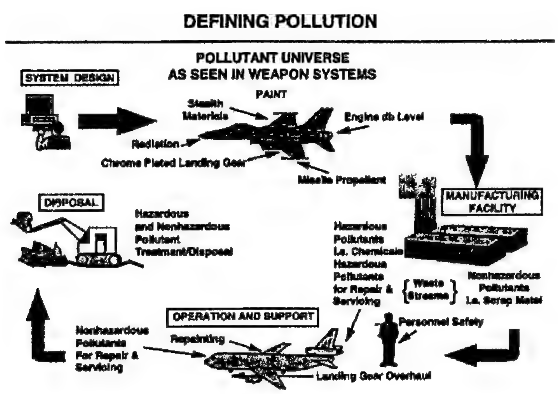

Figure 3-4. Pollutant Universe

Groundwork for environmentally sensitive systems of the future is being laid now. The Armstrong Laboratory, specifically the Logistics Research Division, is currently working on an Aerospace Generation Equipment (AGE) concept called "Green AGE." Once developed, DoD users will have effective AGE equipment with reduced undesirable emissions.[20] Much of this type of "green" work by the Air Force will have far-reaching effects well into the next century.

Miniaturization

Making items smaller has distinct logistical advantages. Smaller items such as "micro-MREs" (meals ready to eat) and smaller, lighter munitions are cheaper and easier to store and transport.[21] Such items would require a less complex logistics system and allow greater ease of transportation. In the future, transportation capability will always be a critical constraint.

Advancements in explosives development may soon allow for weapons with as much as ten times the destructive force of today's weapons while weighing only 10 percent as much as current weapons.[22] The logistics trail of such smart munitions will certainly be smaller and less complex due to reduced handling requirements and much less space needed for transportation.

Micro-MREs are self-contained meals the size of a vitamin pill that contain all essential nutrition and calories to sustain a person for a 24-hour period (fig. 3-5).[23] This would obviously help in battlespace logistics with storage and shipping requirements as well as a lighter load for the individual soldier, sailor, marine, or airman. Advances in nutrition and food packaging should make this technology possible by 2025.

Figure 3-5. Food Pill

The National Aeronautics and Space Administration (NASA) is doing considerable research on foods for space flights, especially that intended for their extended-duration

orbiter (EDO) missions.[24] As expected, weight and volume are critical factors for every piece of hardware placed onboard the shuttle orbiter. As a result, the weight allowed for food is limited to 3.8 pounds per person per day which also includes one pound of packaging material needed for each individual.[25]

NASA's research to make foodstuffs more weight-and-volume efficient includes work on rehydratable items that use water made from the orbiter's fuel cell system, which produces electricity by combining hydrogen and oxygen. Ongoing work involves thermostabilized (using heat to destroy deleterious microorganisms and enzymes), intermediate moisture (foods containing 15–30 percent water) and irradiated foods to reduce the overall bulk of needed meals.[26] The logistician of the future will surely be able to capitalize on these concepts to feed the troops as well as to help reduce the overall logistics footprint.

The only countermeasure to the small smart bomb lies within the development of new, extremely strong shielding materials. There are no countermeasures to the micro-MRE except that they should probably not be used on a routine basis due to morale considerations.

Both of these technologies could be employed basically as they are today. The idea of miniaturization could be applied in both joint and combined environments in peace and during war. Also, both of these concepts could be easily used in the just-in-time logistics concept mentioned above. Fewer people would be needed to handle smaller and lighter equipment and/or supplies. Therefore, a simpler and smaller logistics system could be employed.

Virtual Materials Manager

Visualization technology for the logistician of the future will "permit human-centered aspects of system operation and maintenance to be simulated and fully verified before hardware is produced."[27] The keys to this virtual world are digitization of product and supply data along with more low-cost computing power.

This technology will allow certain aspects of logistics to be modeled with much greater realism and larger consequence than ever before. An example might be the movement of military material through aerial ports that could be simulated graphically to identify bottlenecks, optimize warehouse space and resource utilization, and manage air and ground transportation functions. This modeling could also allow logisticians to have real time pictures of the status of critical cargo items in transit, port and depot operations, and airlifter/sealifter locations across the globe.

The benefits of the logistician of the future using visualization technology can be directly tied to logistics planning. The reduction of the weight/volume of logistics support needed for deployment will be a requirement in more than one alternative future as indicated in the ***2025*** study. In the past, logistics support was a "push" phenomenon that moved thousands of equipment/supply items toward an end-user regardless of specified demand. This ensured a high degree of readiness at a very high cost. Logistics simulation based on virtual reality will help to develop a more efficient "pull" process that allows specific items to be dispatched and tracked separately, that is, just-in-time to be effective.[28]

Transportation

Transportation plays a crucial role in our efforts to logistically facilitate a commander's strategy rather than constrain it. Simply stated, transportation is the means by which we get things from *where they are* to *where they're needed.* Equally straightforward is the objective of any transportation system; getting things from where they are to where they're needed *faster and cheaper*—faster because other events or processes are typically delayed until the arrival of the thing being transported and cheaper because of decreasing dollars available to support an increasingly transportation-dependent

military. Three basic drivers of any transportation system are (1) how much material requires transportation, (2) how far the material needs to be transported, and (3) how fast a mode of transportation can deliver the material.

Our Feet Are Too Big

Current transportation requirements are based on a prerequisite for large amounts of personnel, equipment, and consumables in order to employ the military instrument of power. To the extent possible, this requirement, or dependence, should be reduced. Regardless of how the future looks in 2025, it is safe to assume we will benefit from reducing the amount of people, equipment, and consumables requiring transportation in order to exert our will.

Reductions in the weight associated with military presence, whether for warfighting or operations other than war, reduce our logistics footprint and hence the overall transportation time required. Essentially, reducing the transportation requirement allows existing transportation systems to achieve both the "faster" and "cheaper" objectives.

Actual methods of reducing the weight of the transportation requirement, or reducing the "ton" portion of a CINC's ton-miles per day requirement, will not be discussed under this transportation section. Reducing the weight of the transportation requirement is only offered conceptually to underscore the fact that multiple avenues for increasing the responsiveness of transportation exist.

Closer Is Quicker

To the extent the weight requiring transportation cannot be reduced, we can attempt to reduce the distance over which the weight must be transported. Reducing the "miles" in the ton-miles per day transportation metric reduces the time required to receive equipment and consumables in-theater. Concepts related to reducing the distance over which the weight must be transported are essentially variations of materiel prepositioning. Although primarily material management methods, the issues are addressed here because the deployment and recovery of prepositioned materiel are dependent upon transportation systems.

The first concept is undersea prepositioned materiel.[29] Vast amounts of materiel currently stored afloat prepositioning ships and prepositioned overseas in warehouses could be stored on the ocean floor off the coast of a region of potential use. The vulnerability of the stockpiled equipment to enemy attack would be reduced compared to current prepositioning as would the long-term costs of leasing ships and warehouses.

Deployment of the materiel to its under-water location would be done using self-propelled smart containers capable of guiding themselves to their final destination after being dropped from their transport system. The drop-off transport service could be provided by any conceivable mode: ship, aircraft, or lighter-than-air (LTA) craft. In any case, the actual drop-off would be conducted covertly to guard the location of the underwater prepo. Ships would be modified to deploy containers internally below the water line. Aircraft would deploy containers from low altitude or drop stealthy containers from high altitudes. Stealthy, heavy-lift, LTA craft could deploy containers and subsequently recover them for intratheater direct delivery under conditions of air superiority.[30] The containers themselves would become intermodal transportation systems capable of navigating to their underwater destination using onboard systems and controls. Upon activation for use, the underwater containers would maneuver to rendezvous with a recovery platform or transport themselves to a beach or port.

Another variation of propositioned materiel is the use of spaceborne modules containing light-weight, mission-essential items.[31] Energy cells, which could serve as ammunition or fuel, would be stored and recharged in space using solar panels built into the container/reentry vehicle. Critical, miniaturized spare parts, medical supplies, and dehydrated food could be stored in space and

arrive directly where needed. Within minutes of request by the user, BRAIN's Otto Auditor and Trans-Actor systems would react. The containers would be intermodal with space transport systems such as the Titan IV system shown in figure 3-6. They would be capable of self-guidance and delivery to a precise location when called upon.

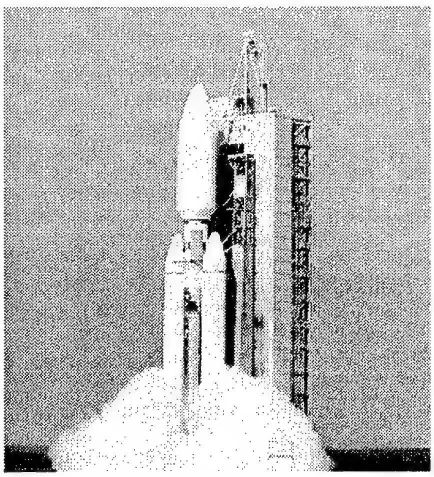

Figure 3-6. Titan IV Rocket and Payload—Spaceborne Prepo

The space module could deliver its entire contents to one location or direct sub-deliveries, depending upon the request. Materials too heavy for transport into space could be manufactured in space from spaceborne resources or debris and stored in an orbit which minimizes transit time.[32]

Think Huge

Beyond reductions in the weight of the materiel requiring transportation and reductions in the distance over which the materiel must be transported, the transportation system itself is called upon to move things faster and cheaper. With respect to transportation platforms, moving things faster calls for some combination of more platforms, larger payloads, and reduced transit times. Specific transportation concepts are not developed under the logistics section since this subject is covered by the air mobility thinking team. Additionally, the Trans-Actor system would be programmed to arrange the most efficient combination of transportation modes based upon the situation. Those transportation concepts that were submitted as part of the ***2025*** study and were considered relevant to logistics, are discussed in appendix A.

Maintenance

Considering the guidance contained in Joint Vision 2010, *America's Military: Shaping the Future,* and the current trends, depot-level maintenance will be privatized in the future. The Air Force supports an amendment to change current legislation (which requires that 60 percent of depot maintenance be performed in-house) to allow for more outsourcing. In 2025, most depot-level work will be performed by private contractors. Base-level or intermediate-level maintenance will remain within the service, with a renewed emphasis on ensuring that mission-essential systems are maintained in combat-ready condition.

Given the increasing costs of fielding new aircraft, extending the operational life of existing weapons platforms will result in retention of aircraft built during the later part of the twentieth century. For example, according to the *New World Vistas* report on materials for the twenty-first century, the C/KC-135, B-52, and C-130 are projected for use well beyond 2025 (table 1).[33] Maintenance of aircraft of this "vintage," coupled with the requirement to support new systems for air and space travel, offers unique challenges.

Challenges relating to an aging aircraft inventory include the replacement or repair of damaged components on the aging systems, countering the effects of the deterioration and corrosion process, and ensuring that the level of maintenance expertise is preserved. These challenges will be minimized through the use of innovative ways of improving reliability and maintainability of new and replacement parts.

Table 1

Fleet Life Extension

Aircraft Type	Number of Aircraft	Average Age	Projected Retirement
C/KC-135	638	33	2040
B-52	94	34	2030
C-5A	77	25	2021
C-141	248	29	2010
C-130 (20 years or older)	439	30	2030
F-15	940	12	2020
F-16	1727	7	2020

Additionally, improved materials, smart systems, and methodology designed to provide the maintenance technician the most comprehensive and up-to-date database, will be essential.

Improved Reliability and Maintainability

Newly developed aircraft will embody more reliable and maintainable systems and equipment. Therefore, intermediate-level maintenance should decrease. As a result, life-cycle costs will become far more reasonable. Aircraft and weapons systems will require far less supply support for parts, fewer personnel for repairs, and less time out of service for maintenance.

Since first implemented in the mid-1990s, the Reliability and Maintainability (R&M) 2000 program has resulted in significant reductions in the cost of integrated logistics support. This program gave reliability and maintenance the same weight as cost, schedule, and performance requirements during new weapon acquisitions and modifications to existing systems.

Under incentive by contracts, vendors have offered more reliable systems and components. These contracts have already resulted in reductions in maintenance requirements for current systems. For example, as a result of modifications and upgrades under this program, the B-52 mission-capable rate went from 38 percent in the early 1980s to over 81 percent during Desert Storm.[34]

Along with improved reliability, system designers must emphasize interoperability in parts and components to further reduce the logistics footprint. As new systems are fielded, composite material enhancements must be incorporated into maintenance on the aging systems to extend their usefulness.

Modular Design

The development of modular aircraft, coupled with highly reliable and easily maintained systems, will minimize logistics requirements and simplify maintenance needs. By capitalizing on modular propulsion and, avionics, and weapon- and flight-control systems, manufacturers will design aircraft that can be easily configured to meet specific missions—even within the battlespace.[35] By standardizing systems as much as possible, we will realize significant savings through reduced production line retooling.

Another promising concept for streamlining maintenance requirements is a proposed redesign of AGE using a modular methodology. The AGE would be designed with all common systems (air compressors, generators, and hydraulics) combined in the same unit. Systems would be designed as modules that could be quickly and easily removed and replaced, allowing for rapid repair or reconfiguration for differing aircraft. Two major benefits of this system are more commonality between bases and less equipment processing during mobility exercises.[36]

Lean Logistics

"Lean logistics" is another current initiative that is contributing to an overall decrease in intermediate maintenance requirements this initiative will prove valuable through 2025. One of the essential premises of lean logistics encourages the use of *current* business practices which have proven successful in commercial application. For example, fostering closer partnerships with suppliers results in a smoother pipeline for parts and support. Today, a benefit of improved relationships

has been the move away from maintaining large inventories of spare parts.

Successes in this area would influence aerospace repair facilities to cease reliance on mass production methods and to adopt simpler, more integrated production systems.[37] The aerospace forces can move away from the costly and redundant just-in-case ideology to the newer and more practical just-in-time philosophy. However, the concept of lean logistics does not preclude stocking a safety level of critical items necessary to ensure the crucial level of readiness required by the armed forces.

To fully realize the benefits of a truly lean logistics system, we need to develop both long-term business relationships with suppliers and a more robust capability to fabricate replacement parts internally. Employing CAD and computer-aided manufacturing (CAM) techniques along with the use of "intelligent" materials which are capable of adapting themselves for use will be critical to on-the-spot fabrication.

Locally Manufactured Parts

The use of CAD and CAM coupled with new and improved materials will allow intermediate maintenance facilities to reduce their dependence on the supply system for parts. A critical component of the acquisition process and subsequent Integrated Logistic Support provided by BRAIN is the requirement to acquire all data relating to specifications, materials, and processes associated with the manufacture of parts when they are initially acquired. This information is subsequently available to the technician through the Virtu-Log subsystem of BRAIN. Consequently, in 2025, each facility will have the maintenance history and drawings for each and every part.

Intelligent materials, both composite and plastic, will be used to fabricate parts. A working group headed by Charles Owen has created computer-generated representations of uses for "nanoplastics." This material is based on the concept of theoretical fusion of the traditional field of plastics and that of nanotechnology. The field of nanotechnology is where microscopic machines and other objects are constructed atom-by-atom.

> Computers the size of a blood cell would be contained within nonplastic material, giving objects enormous processing power ("intelligence"). Sensors and emitters would be constructed to absorb and transmit pressure, sound, and nearly the entire electromagnetic spectrum. These would provide nanoplastic materials with the ability to sense their surroundings and to respond with physical change or the transmission of sound, light, heat, or other emissions.[38]

The *New World Vistas* white paper on materials provides another method of composite fabrication that involves the direct spray-up of molten metal droplets onto a final shape to provide rapid solidification.[39] Further research in these two areas may significantly enhance the ability of 2025 technicians to fabricate replacement parts themselves.

Robotics Technology

Automated, or robotic, systems should streamline maintenance functions. Today, a robot system called the automated aircraft rework system (AARS) is being used to remove several types of fasteners on F-15s at Warner Robins AFB. Designed and integrated by Mercer Engineering Research Center (MERC), this system locates, identifies, maps, and removes wing fasteners. After workers repair or replace wing panels, AARS drills holes and reinstalls the fasteners. This automated system can do in one day, what it used to take a team of technicians one week to accomplish.[40]

A "machine vision system" locates, identifies, and sends data to a control computer. The computer stores a map of the wing. Using a form of artificial intelligence, the robot decides whether to unfasten or drill a screw. A laser system keeps the tooling perpendicular to the wing. Given the success of this system, similar systems will be developed in the future to include routine

functions such as changing tires, brakes, and lubrication. The cost of building new aircraft will be significantly affected by this new technology.

Neural Networks and Artificial Intelligence

A developing technology—neural networks—may provide a revolutionary capability for maintenance diagnostics that will significantly affect logistics support. Neural nets develop diagnostic strategies by learning from past experience with the system. Today, there is no system capable of accomplishing maintenance using this technology.[41] However, in 2025, the maintenance technician will couple his or her own experience with that of a neural network diagnostic system to cut maintenance time and costs. Troubleshooting technicians will use programs that analyze the problem and the maintenance history of the equipment. These programs will then perform diagnostic tests and make maintenance recommendations to the repair technicians.

The system would assess parts availability and order whatever was needed to repair the system or component. Each aircraft or weapon system would have a record much the same as a medical chart. With each visit to the "hospital/maintenance facility," any tests, diagnoses, repairs, or installations of new or reworked parts would be entered on this record. For each piece of equipment, the record would be available to any technician anywhere in the world or in space.

Another important area of maintenance at the intermediate and local level is that of processing engineering and maintenance changes to existing systems. Technicians need up-to-date information regarding processes, parts, and supply support. The information system supporting this process should ensure immediate system response. Data changes must be made to all data bases—and data must be audited globally for accuracy and synchronization. Our neural network will integrate automated support tasks such as those described above.

Smart Parts

Another means of reducing the logistics footprint from maintenance requirements involves using information systems to analyze existing data to establish spare parts inventory levels. For example, by using chips in parts (making them "smart parts"), we could make each and every spare part a part of the information system.[42] Chips could be used in key components of aircraft to tell us when they have reached a true point for maintenance needs.

Smart part aircraft would continuously run diagnostics upon themselves. These parts would have the ability to link into the BRAIN system to assess replacement availability in the event of pending failure. At any time, even during flight, when the part anticipates a problem or the end of its useful life, it would report itself as failing and would automatically "check" the system for replacement. When the system landed, the ground maintenance personnel would analyze the automated report to determine the health of the system. In the event of a failure or pending failure, the supply request would already have been generated and timely repair could be accomplished.

Simple measures, such as total stress or total cycles, would be more effective measures than today's which made use of airframe or engine hours. Other useful parameters are mean time between corrective maintenance actions, mean time to repair, mean requisition response time, and gross effectiveness. Proper analysis of these parameters could result in significant inventory-levels reductions.[43]

Virtual Reality

Virtual reality (VR) will provide the means to make maintenance technicians capabilities *virtually* limitless. With the requirement to maintain aging aircraft as well as state-of-the-art systems both at home base

and when deployed, the maintenance technician will require an encyclopedic level of knowledge. Not only will VR be a valuable training tool to initially train technicians; it will be a valuable tool on the battlespace when technicians could be faced with problems they have never encountered before.[44] By using VR technology, we can make training realistic. It would be the next best thing to actual "hands-on" experience.

A virtual reality library that contains complete information for every system would be easily transported to the battle-space. This information would provide a visual 3-D picture, complete with audio guidance on every platform and system in use. This system would enable maintenance technicians to assess battle damage by comparing the damaged component or system to one in perfect working order. Because VR is interactive, the technician could query the system to learn how to repair or replace things. Virtual reality will enable every technician in the battlespace to effect repair on any system.

Interface with Combat Readiness Systems

The logistics system of the future will provide a direct link to the system that measures unit readiness. This system measures unit readiness in many categories and for different missions (see "Combat Readiness" white paper). When a system is down for maintenance, whether routine or emergency, the logistics database will provide the necessary information to the readiness system. The commander will be provided an estimated time for repair and notification of any supply support problems that may impact the process.

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Chapter 4

Concept of Operations

Our vision is of a logistics system of systems that provides total asset visibility yet is transparent to the regional commander in chief by facilitating rather than constraining strategy. This vision is best illustrated with a notional vignette.

Scenario

"How are my birds tonight, Sue?" The second shift of unmanned aerial vehicle (UAV) flyers were making their way into the control room and Maj Helms was preparing to take over Sue's spot at the controls.

"Started with four, ended with four," replied 1st Lt Sue Sloan, the Air Force's only UAV flyer with a confirmed air-to-air kill.

"How'd the first flight on the new model go?" asked Maj Helms. "Those new smart parts give you any trouble?"

"Hardly! In fact, they're the reason you've got a four-ship flight and full coverage tonight. About two hours into the sortie, I got an ether message from Otto Auditor, the gate keeper of that BRAIN thing it told me we're authorized to manufacture and install a new wing-form actuator circuit at Samsong's expense. Funny thing is, it was just an info copy to me, explaining how the bird itself, tail number 2025, had requested the new circuit, received contractor funding for the warranted part, scheduled the installation, and arranged for disposal of the old part."

"Well Sloan, now I know why they limit our time on the console, because you're not making any sense to me. I think you've been staring at the old CRT a little too long."

"See for yourself, sir. Use the gloves after you authenticate and go virtual. Then grab the new bird." "Slow down Sue, you know I don't like these virtual reality gloves." Major Helms grudgingly pulled on the VR gloves and grumbled a terse human factors evaluation, "You can't eat fried chicken with these things on." With the gloves on, and his authentication complete, Major Helms furrowed his eyebrows and said, "All right, they're on and I'm in. Who are all these people, Sue?"

"Well, they're not really people, sir. They represent the systems our new bird's been talking to. Spill the graphical history bucket and you can see everything that happened in about a one-minute animation. There, see how the smart part detected that the wing-form actuator circuit was out of spec and reconfigured the card to compensate?"

"Yeah, it's supposed to, isn't it Sue?"

"Sure, but look what happened next. The smart part tells Otto to come up with a replacement. Otto, the gatekeeper for the logistics system of systems they call BRAIN, then validates the smart part's request and talks to Red E. Ness to establish our priority, Budge-It to see if there's money, Man-Per to ensure we've got the people to change out the part, and Add-r-Quit Space to see if we've got the facilities to change the part. Meanwhile, Red talks to FAR-Ther and Done Deal, the acquisition and contracting systems, and figures out the circuit is still under warranty. Not only that, but our priority is so high, Trans-Actor says we can make the part in the agile manufacturing unit (AMU) instead of dropping it in with tonight's delivery. So, Red has Samsong beam the manufacturing file to the AMU and the part is made in the field at their expense."

"Hey, where'd the old part go, Sue?"

"Sir, it dropped out of the bird and into Dispose-All, who arranges for repair, return, or disposal."

"Well all right Sue, so now machines have complete control?"

"Not completely sir, see that guy over there?"

"Yeah, who's he, another system represented by one of your people graphics? By the way Lieutenant Sloan, I think your virtual reality icons are a little too . . ."

"User friendly sir? Their all within reg, but I can make them more user unfriendly if you like."

"Never mind; just tell me what system that old guy over there looking down on us represents."

"That's not a system sir. He represents the human analysts who oversee the system and work out conflicts the systems can't solve."

"Oh! Well, that seems like a good idea. I suppose you could have asked the analyst to work your *wing doufer* problem?"

"Not likely sir, Otto sent me the ether message summarizing everything that had happened twelve seconds after the smart part requested the new part. And he wasn't even sweating."

"Sweating?"

"Yes Sir, the Otto icon sweats if your task uses more than two tenths of a percent of total throughput . . ."

"OK Sloan, I get the picture. Now I want to fly jets. I've got a mission to do, you know." Major Helms was settling into the console when he shook the sensor-cueing device and said, "I've got it."

"Pardon me, sir?" Lieutenant Sloan wasn't sure what the Major meant by that and she certainly wasn't convinced he had a handle on all the features of the new bird, let alone the BRAIN it interacted with.

"Oh never mind, Sue. Hey, when's all this new stuff gonna make our job any easier?"

"Consider it done sir!" she answered.

This scenario represents a problem that was completely solved through use of the automated features of BRAIN. Human intervention was not required in this instance; however, with a minor change to the scenario, we can demonstrate a "human" interface. In the revised scenario, the part is no longer under warranty and there are no funds available to fix or replace it. At that point, the analyst with logistics oversight responsibility for Lieutenant Sloan's organization would become involved and communicate with the "budgeteer" responsible for funding Lieutenant Sloan's equipment. If they determined that the requirement was sufficiently critical, they would "reprogram" funds to pay for it. The analyst would update the system and Budge-It would reflect the new funding.

Chapter 5

Recommendations

Despite the changed political, economic, and technical environments of 2025, the mission of providing logistics support for air and space forces remains constant. What *does* change in 2025 is the logistics process for providing that support. The process will be responsive, automated, and integrated. It will be so routine that it will not present a persistent worry to the CINC, who may be tasked with missions ranging from humanitarian relief to total war.

Whether the logistics mission of the future is service-specific, DOD general, or contracted out is irrelevant. Survival of the logistics process depends on taking advantage of the technologies discussed and on developing an automated system which provides instantaneous, automated, cross-talk capabilities among functions.

A System of Systems

The logistics system of systems—BRAIN—is fully automated. It seamlessly integrates all phases of the logistics process. It provides the operator total visibility of all assets from cradle (acquisition) to grave (disposal). Commanders can rest, assured that all platforms they require will perform. They will know that their equipment will be supported by well-trained personnel who have the necessary parts, equipment, and facilities readily available. Improved reliability and interoperability of systems and their replacement parts will reduce downtime and requirements for routine maintenance.

Technologies

No longer will a requisition fall into the "black hole." The excuse, "the part is on order with no specified delivery date" disappears. Smart parts will self-diagnose problems and automatically generate reorders. Smart parts, agile manufacturing, and a "just-in-time" partnership with industry will provide rapid resupply capability.

The foundations for the systems and processes described herein are being explored today. The BRAIN system relies heavily on advancements in the areas of artificial intelligence, connectivity of automated systems, and hardened communications capabilities. Many initiatives throughout government and private industry seek to improve these technologies.

Agile manufacturing techniques that use lasers and molecular materials are under development in military and commercial labs. The ability to manufacture "on the spot" provides an added dimension of flexibility and holds great promise for future employment. Virtual reality is another hot technological commodity. The potential uses for this capability are being explored on many planes. The amusement industry has embraced the concept and is providing creative games to stimulate the imagination of youngsters. The military is already providing virtual aircraft mock-ups to test aircraft designs.

Integration

While these technologies are critical to a successful logistics system in 2025, changing the attitudes within the communities that interface with the logistics community will be the essential "first step."

A fully integrated logistics system will upset many rice bowls. Today's functional stovepipes create a disjointed and counter-productive logistics process. The success of the logistics process depends upon a radical change in the way all disciplines adapt to sharing information and that they accept a different way of doing business. Strong, decisive leadership is required to break

down functional barriers. However, once these barriers are destroyed, a new road leading to an enhanced logistics process must be paved.

Investment

The initial investment will be great, both in terms of changing the hierarchy and the cost of buying the hardware, software, and training to support the system. The payoff will be enormous in terms of reduced staffing, costs, and efforts to support the aerospace forces of 2025. The overall cost can be reduced by delaying implementation of a new system until after the required technologies have been proven in other areas. By waiting, we may be able to adapt commercially available systems to a military application. This must be weighed against the cost of lost opportunity.

Skills Mix

Skills requirements within the aerospace forces will shift substantially. The requirement for "hands on" contracting personnel is substantially reduced. Most pricing, bid solicitation, and analysis are performed electronically. Experienced acquisition professionals will still be required to solve problems the system cannot address. The increased use of computers, the need for complex software, problems arising from system integration, and a greater need for computer security may result in a shift from traditional logistics disciplines to personnel with skills in the areas of computers, operations analysis, and communications security. Additionally, staffing levels for materiel management will allow one person to manage many more items than they can currently manage.

Conclusion

In conclusion, we must develop a computerized system that is fully responsive to commander needs. We must capitalize on the emerging technologies. We must integrate all functions in the logistics chain. A commander may have all of the newest technology to accomplish any mission in the future; however, without an automated, fully integrated logistics support system, he may be limited by the same challenges he faces today. The expense of implementation can be minimized by procuring technologies developed by industry. By integrating the system we have described with the new weapons and aircraft that will be available in 2025, the commander will *always* be able to report to the president, "Consider it done!"

Appendix A

Lift Platform Concepts

Additional lift platforms could be acquired through the development of a low-cost, lighter-than-air craft or a modular, multimission aircraft. As an extension of earlier LTA accomplishments (such as the US-built dirigible *Akron*, launched in 1931 with a gross lifting power of over 200 tons), a modern LTA craft could be designed. It would use lighter but stronger materials and miniaturized equipment to significantly reduce the empty weight of the craft and achieve useful lift capabilities of 100 tons.[1] Additionally, the lower cost of the LTA craft, loosely estimated to be one-twelfth the cost of modern cargo aircraft, would allow for larger numbers of these craft to be acquired for the same cost.[2]

Similarly, the modular medium-lift aircraft concept calls for a multimission-capable, high-aspect-ratio, flying-wing aircraft. The aircraft would serve as an airlifter, tanker, or strike platform, as needed, depending on the type of load module installed. Load modules would be completely intermodal, thus ensuring compatibility with other transportation platforms. Potentially, the multimission-capable aircraft could allow for an increase in the number of aircraft apportioned to airlift and refueling during the lodgment and redeployment phases of a campaign.

Increased transport payloads could be possible through use of wing, in-ground-effect (WIGE) technology (fig. A-1).[3]

The largest known WIGE aircraft was produced by Russia's Central Hydrofoil Design Bureau and is a 400-to-500 metric-ton (881,600–1.1-million-pound) aircraft.[5] Advancements in materials and engine efficiencies could allow extremely large payloads. With near-real-time meteorological and sea-state data, these heavy-lift

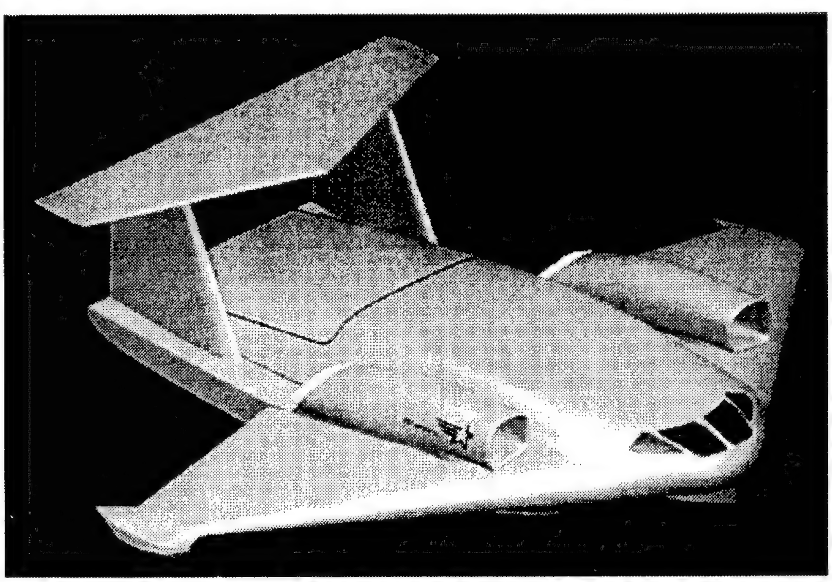

Figure A-1. Conceptual Wing in-Ground-Effect Aircraft[4]

platforms could skim the ocean's surface at very low altitudes and circumnavigate adverse weather conditions.

Concepts capable of enabling faster equipment transport include super-efficient aircraft engines built from advanced materials using endothermic fuels and sophisticated, intermodal, standoff cargo containers. These advanced engines could provide a 100-percent increase in thrust-to-weight ratio and a 50-percent reduction in fuel consumption.[6] Increasing the thrust and fuel efficiency of aircraft engines would allow greater cargo loads and reduce the need for enroute refueling. Additionally, sophisticated, intermodal, standoff cargo containers could eliminate the need for transportation aircraft to land and unload their cargo. Future containers would be air-dropped—and smart enough to navigate to a precise location on the ground. Additionally, they would be capable of limited self-propelled ground movement, and self-loading on other transportation systems. Their contents could be determined by plugging an information scanner into the container's data port or by initiating a holographic image display. By eliminating the need to land the aircraft for unloading at its destination and reducing the equipment required to handle the containers during aircraft loading and on the ground, delivery time and costs could be reduced.

Notes

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2. Ibid.

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Dynamic Response Logistics: Changing Environments, Technologies, and Processes

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Executive Summary

Logistics management is the integrated management of the functions required to acquire, store, transport, and maintain the materiel necessary to support combat forces. The task of the military logistician is to establish the appropriate balance among these functions to achieve the required level of operational support while consuming the least amount of resources. Future logistics concepts will evolve primarily from recognition of new **environments**, **technologies**, and **processes**.

The use of self-repairing and self-reporting parts will greatly reduce both the proverbial logistics "footprint" and decrease the logistics "tail." Multiuse packaging, in which packaging combined with a catalyst produces either a fuel or food product, will reduce additional shipments of items into the theater of operations. The Battlefield Delivery System (BDS) with a standard shipping container will provide a seamless transportation system from the commercial vendor to the theater of operations.

The concept of a container aircraft will increase the flexibility of the BDS concept and become an integral part of the agile base concept, where the container aircraft's cockpit becomes a command and control center with its engines providing electrical power to the base. The Mobile Asset Repair Station (MARS) will support the remanufacture and repair of avionics and components in the theater of operations using a mobile facility with fully integrated flexible manufacturing systems and robotics systems linked to commercial manufacturers.

Logistics operations of the future will operate under an integrated, flexible, and seamless system from vendor to battlefield which will govern logistics decisions and operational strategy—a system called **dynamic response logistics**.

Chapter 1

Introduction

Logistics, combined with strategy and tactics, will continue to shape command planning and decisions into the future. Commanders will continue to have "the responsibility to create, to support, and to employ combat forces."[1] Logistics will play a major role in the command of aerospace forces through "the creation and sustained support of weapons and forces to be tactically employed to attain strategic objectives."[2] As Douglas Menarchik states,

> Logistics affects military strategy, military strategy affects grand strategy, and grand strategy affects political outcomes. It raises important issues for America's security policy in the post-Cold War era and is worthy of leadership interest to ensure America's logistics is in order. America and the international community need to pay more attention to logistics infrastructure, doctrine and its effects on strategy, tactics and military-political outcomes.[3]

A task at hand is to reduce the logistics "footprint" and decrease the size of the logistics "tail." This statement is easy to articulate but challenging to achieve. The paramount goal for the military logistician in 2025 is to provide a responsive, agile logistics system to support military operations in an effective and efficient manner—**dynamic response logistics**. A critical requirement for any logistics system in 2025 is that it operate similarly in both wartime and peacetime environments.

Logistics management is the integrated management of the functions required to acquire, store, transport, and maintain the materiel necessary to support combat forces. The task of the military logistician is to establish the appropriate balance among these functions to achieve the required level of operational support while consuming the least amount of resources. B.S. Blanchard states,

> The requirement to increase overall productivity in a resource-constrained environment has placed emphasis on all aspects of the system/product life cycle, and logistics has assumed a major role comparable to research, design, production, and system performance during operational use.[4]

Air and space missions and the requirement for specific types of logistics support will undoubtedly change over the next 30 years. While the future remains uncertain, a number of trends appear likely to affect the mission and logistics support areas:

- more varied, regional operations;
- potential for multiple simultaneous operations;
- increased privatization and outsourcing;
- more tightly integrated operations among the Air Force, Army, Navy, and Marine Corps.

The military logistician will respond by altering and implementing evolutionary and revolutionary logistics processes to achieve the required level of support.

Environment, **technology**, and **process** changes have enabled military and business logisticians to significantly increase support while achieving dramatic reductions in total cost. For example, deregulation of transportation modes in the 1970s and 1980s allowed organizations to achieve higher levels of customer service through the trade-offs of inventory and safety stocks for faster, less expensive, and more reliable transportation. Changes in technology and information management have resulted in logisticians trading "inventory for information" and using more timely information to anticipate customer requirements. Process changes have also significantly affected logistics support by reducing cycle and repair times, reducing nonvalue-added interfaces and transactions

occurring among logistical functions, and more clearly focusing on those activities that provide the greatest value to the customer.

The environment, technology, and process innovation will continue to act as the major agents of change within military logistics. The environment will shape logistics practice through changes in air and space missions, resource availability, and business logistics practice. Technological changes and improved information management will allow the logistician to bring state-of-the-art decision making and hardware to bear on logistical problems. Process changes will streamline the flow of materiel from source of supply to the ultimate customer. The future logistics structure will be dominated by a "pull" process rather than the predominate "push" process in use today.

These change agents will radically alter the activities employed by the logistician to support the core competencies necessary for attaining the war-fighting commander's strategic and tactical objectives. As James Huston states in his 1966 classic *The Sinews of War*, "it is no use engaging in a dream world strategy divorced from logistical feasibility."[5] Dr Paul G. Kaminski, undersecretary of defense for acquisition and technology, states, "What we need is vision, leadership, commitment, and stakeholder engagement on the part of the war fighters, logisticians, developers, and industry."[6]

Notes

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Chapter 2

Changing Environments

By the mid-1990s, changes in the environment in which military logistics operates are already blooming. By 2025, the fruits of these changes will transform the current logistics system into one barely recognizable as a peculiarly military system.

The environment has been especially affected by three significant changes. First, the end of the cold war has impacted the structure of a military force which had for a generation been prepared for a global struggle against a powerful adversary, including the possibility of widespread nuclear war. Second, commercial business practices have undergone major modifications as companies have focused on quality, productivity, and international competitiveness. Finally, as a subset of business, logistics processes have benefited from greater attention paid to customer service, leaner organizations, and strategic alliances. All three changing areas will influence military logistics in 2025.

Military Changes

With the disappearance of the Soviet Union as the United States's (US) central adversary, scenarios for future wars will likely focus on ethnically and nationalistically based regional conflicts rather than global conflicts, with the possibility of simultaneous regional conflicts. Thus the US must plan for quicker, more intense, and conceivably more lethal wars. The US may find that higher proportions of logistics needs are related to various humanitarian missions, interspersed with brief but intense sessions of supporting battlefield needs.

The US will develop dynamic response logistics support, capable of both rapidly tailoring logistics support packages to particular circumstances and responding with standardized kits for shorter, higher tempo operations. As recent US military operations have shown, there will be more work with and support from allies. However, the US must be prepared to muster a force independent of that provided by allies, either from collateral assistance by way of direct support (troops and material) or through indirect support (basing rights).

The growth of the joint responsibilities for many logistics functions—the roles of the Defense Logistics Agency in supply and distribution, the Defense Contract Administration service in contract administration, and the Defense Finance and Accounting Service for billings and payments—demonstrates an inexorable trend toward a unified and consolidated military logistics system. Only a systems approach to all military logistics operations will achieve organizational harmony and interfunctional integration to work seamlessly across the Department of Defense (DOD).

Because logistics support systems will no longer be service-, or even country-specific, all US military systems will be supported by a joint logistics system that will also be designed for compatibility with those systems operated by allies. Interoperability and interchangeability will be essential not only for major system components, but also for many of the databases and information systems used to manage materiels.

Business Changes

The environment in which US businesses operate has changed dramatically in the last decade. A tendency toward government deregulation (especially in the transportation and communications areas), relaxed enforcement of antitrust laws, giant strides in telecommunications capabilities, widespread availability of computers, and

an increasingly competitive environment have all had a significant impact on the conduct of private enterprise. Quality techniques such as "value added" have led to a reexamination of business practices and a reengineering of processes. These efforts have led to leaner and more productive organizations.

The defense industrial base in the private sector has not been spared the effects of these trends, and downsizing in defense industries has meant the loss of thousands of jobs since the late 1980s. When coupled with a result of the changed military environment, a dwindling number of weapon systems are being procured, creating a question of the viability of the US private sector manufacturing base as private defense production becomes a riskier business. Thus, principal contractors are rapidly becoming a conglomeration of airframe and electronics firms. This diminishing number of principal vendors of systems and subsystems will affect numerous subcontractors in the US industrial base, as the make-or-buy decisions of the prime contractors will lead to far fewer suppliers in the nation for subsystems, components, and spare parts.

Although the demise of many manufacturers has helped solve the problem of overcapacity in the industry, it is unlikely that weapon systems production will rise to the levels required to keep even the few remaining factories operating at efficient levels. Attempts to use foreign military sales to offset US purchases will only slightly compensate for the decline in US military procurements. Consequently, there will be greater competition for any work that may help keep the private industrial base alive. To avoid an inefficient private defense sector, there will be pressures on the organic depots, which themselves are already operating at lower levels of productivity, to release work for privatization and outsourcing. The DOD routinely reports to Congress that outsourcing to the commercial sector typically lowers costs by 20 percent.[1] This 20 percent savings would free over $3 billion per year for higher priority defense needs, such as those advocated in this paper for logistics in 2025.[2]

Logistics Changes

New ways of doing business in logistics in the private sector have already had a significant effect on military logistics and will continue to do so in the coming years. In a study of firms rated excellent for their logistics practices, P. M. Byrne and W. J. Markham observed that logistics excellence is a management imperative for the future.[3] The benefits of logistics excellence, according to Byrne and Markham, are improved quality and service levels, faster cycle times, greater efficiency and productivity, and improved customer-company relations.[4] Practically speaking, this concept has meant developing win-win relationships with suppliers, carriers, and customers.

Logistical excellence in the future military logistics context will involve these recurring themes from the above discussion: outsourcing, strategic alliances, flexibility, focus on customer service, and state-of-the-art information technology. Adopting such a scheme means that the US must extend the concept of an integrated logistics system beyond the traditional barriers of the military logistics system to include vendors, manufacturers, and the ultimate users. Many authors have commented on the need to form strategic logistics alliances or coalitions.[5]

Military logistics uses a wide variety of unique systems, data, equipment, and materiel to support its customers. Examples include inventory management and reporting systems, military standard requisitioning and issuing procedure (MILSTRIP) formatted requisitions, specialized equipment such as forklifts and pallets tailored to specific aircraft, and the need for a variety of spare parts. These systems pose many problems even during

peacetime operations. The unique systems result in redundant information systems in multiple sectors, additional time and handling of materiel, duplicate bar coding and item identification, loss of in-transit visibility, and difficulty in identifying equivalent parts or items due to the conversion from national stock numbers to manufacturers' part numbers. The system in use in 2025 must be fully integrated and streamlined with the commercial sector. This system will allow the air and space forces to obtain information directly on the status of inventory items at the commercial supplier.

The application of dual-use technologies will become increasingly critical to future logistics support due to the costs associated with specialized parts. Some unique military logistics technologies have proven costly and difficult to field, and pose significant problems when interfacing with other military services or the civilian sector. The military has also grown increasingly reliant on business logistics for the movement of materiel, and logistics processes must be able to "plug and play" with the civilian distribution systems to ensure visibility and reduce cycle time and cost.

The use of third-party suppliers of logistics that has become commonplace in the private sector in the 1990s will continue to be an attractive alternative in 2025. This concept means turning to private enterprise to provide the logistics services that have traditionally been an organic part of the military. This movement toward privatization will affect all military services, and as a common logistics structure will be sought to support the reduced DOD organizational structure. Cost-based and performance-based measures will be used as a basis for privatizing specific logistics functions. The increasing reliance on private carriers for moving military materiel, the use of commercial items, and the privatization of the depots are the harbingers of future logistics operations.

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Chapter 3

Changing Technologies

Technology advances will drive some of the greatest single changes to logistics in 2025. Technologies, especially in communication and data transmission, will change the face of logistics and make possible new organizational structures. New technologies will include many that are already in use in the civilian sector, such as FedEx's ability to monitor the delivery progress at the item level.[1] The changes in this area will be so great as to result in a qualitative difference in the way logistics is applied.

Integrating operations across distribution channels requires flexibility to switch rapidly from one mode of transportation to another based on availability of transportation and the need for assets. Inventory will be containerized and kept in motion rather than stored in a fixed warehouse. Battlefield support of the future will depend upon both military and commercial transportation built upon a network of standard shipping containers utilizing automatic identification technologies and radio frequency identification (RFI), coordinated through electronic commerce and global communications capability.

A. Braithwaite and M. Christopher discuss the need for global logistics and supply chain-management strategies, and summarize the central elements of each. They list several factors as critically important to the development of global supply chains, including extended supply lead times and uncertain transit times, multiple freight modes, and opportunities to ship intermediate components for local assembly. The greatest challenge, in their view, is to determine what information is needed for a global supply chain strategy and to use it effectively for planning. According to Braithwaite and Christopher, "the management of global logistics is in reality the management of information flows."[2]

Information Technology and Systems

Perhaps the largest change in technology affecting logistics in 2025 will involve information technology, bringing major improvements in the management of logistics operations. Integration of information systems across the DOD will allow integration of logistics functions and processes across services. The changes in information technology will enhance the ability to monitor the location and condition of materiel at whatever level of granularity required for the given items and the situation. Information technology changes will also permit decreased inventory through increased ability to requisition materiel quickly as needed, while reducing the number of people to support this vital function. Standardized, built-in marking of acquired items will be tied to information technology to support quick identification and routing of items as satellite monitoring of location becomes routine. Consolidated information systems will allow real-time monitoring and routing of items.

Full visibility of the logistics pipeline, or complete supply chain visibility, will be coupled with more sophisticated capabilities of monitoring logistics needs. This change will result in direct delivery of needed supplies from stateside suppliers directly to the point of use.[3] The massive buildup of supplies, with a mix of known and unknown container cargoes and needed as well as unneeded items, as seen in Operation Desert Storm, will be a condition of the past. Better information will result in tailored delivery of the right supplies, at the

right location, at the right time, and in the right condition. This concept will be facilitated through the use of flexible manufacturing systems (FMS) driven by computer-aided design and computer-aided manufacturing (CAD/CAM). Warehouses full of excess, obsolete assets have no place in the logistics system of the future. This outdated concept of "just-in-case" inventory control will no longer be feasible in constrained budgetary climates. Instead, items will be produced on demand from information stored in databases especially designed to support FMS machine tooling and set-ups, and free-form manufacturing.[4]

Innovative applications of the new information technologies in the areas of logistics management will impact logistics support in 2025 at all levels of the logistics process from how logisticians are internally organized (micro) to how they interface with other organizations (macro). At a macro level the continuing confluence and merging of computers and communications is changing how organizations are economically organized. Modern information technology reduces transaction costs and hence makes it more economical to use market forces rather than internal and organic processes to acquire and deliver logistics support.

Information technology is also giving rise to new organizational structures referred to as virtual corporations or networked organizations. Commerce through the Internet is exploding as the Internet is commercialized and new economic structures (such as electronic virtual money) are developed to facilitate such transactions. Electronic markets are forming to facilitate the distribution of spare parts in the airline and automobile industries. Through these developments, a more direct contact between the units in the field (customer) and the ultimate supplier will be realized.

At the micro level, information technology is revolutionizing how logistics support is delivered in the field. Revolutionary technologies, and their equally revolutionary application, such as virtual reality (VR), genetic algorithms, fuzzy logic, neural networks, and artificial intelligence robotics, will dramatically change how and where logistics support is provided. Not only will VR be used to develop and test logistics maintenance procedures and to train technicians, but when combined with adaptive programs in the form of artificial intelligence, maintenance will be remotely provided with minimal direct human involvement. These technologies combined with robotics will make space logistics truly feasible.

Robots will be placed in space controlled by software that can learn and adapt as it gains experience. This capability combined with VR can easily lead to remote maintenance of satellites. This concept is a further adaptation and refinement of a similar idea highlighted in *SPACECAST 2020*.[5] Adaptive robots can, on their own, learn to diagnose and perform most maintenance functions, and this intelligence can also be used as a buffer (along with VR) for time lags in communications between satellite orbits and the earth's surface. VR would allow maintenance troops on the surface to "follow" robotics maintenance actions instead of waiting for direct signals from space to confirm what actions are taking place. VR would also reduce bandwidth needed; the only required signal would indicate actions taken by the robot. Hence, there would be no need to send visual images, because VR will provide visual realization. Reduced signal requirements would in turn mean quicker updates and reduced time lags due to processing.

Through revolutionary advances in information technology, more "smart" parts will be developed in the future. Recent work in the area of miniaturization has highlighted the feasibility of installing smart chips onto components.[6] Smart chips built into a part will track operating hours and current condition, as illustrated in figure 3-1. Not only will these smart parts

diagnose themselves, but they will order their own replacement parts if the damage cannot be repaired. These "self-reporting" parts will have the capability to determine when they are operating in a degraded mode and send a signal directly to the commercial manufacturer who will build or ship the replacement part on demand. This system will bypass the traditional aircrew debriefing, maintenance troubleshooting, and supply reordering scenarios currently in practice. The feasibility of self-reporting parts is currently being addressed and has been identified in several recent books, one by Bill Gates, and another by Nicholas Negroponte, in which smart parts are described as active labels.[7]

New World Vistas also includes a discussion of "self-monitoring and self-healing materials to permit in-flight battle damage repair."[8] While remote diagnoses and sensing of maintenance problems will be possible, neural nets and parallel processing will allow systems to reconfigure themselves around defective areas, becoming "self-repairing" parts, as illustrated in figure 3-2. The self-repairing part has the ability to detect degradation in performance and repair itself by eliminating the failed component from use or rerouting its circuits around the defective area. This concept will operate as a standby redundancy system, whereby the spare components or circuits are operated only when required to keep the part functioning. The maintenance strategy used will be that of nonmaintained redundancy. As such, the repair is only commenced when the part completely fails. It will be more cost-effective to build this self-repair capability into the parts, even with its redundant circuitry, rather than removing, repairing, and replacing parts in a cyclic pattern over the useful life of the part.

Packaging and Battlefield Delivery

Packaging material will continue to be a critical concern to future logisticians. Packaging includes several functions such as protection, ease of handling, information about the packaged product, stowability, temporary storage, and protection against tampering. Future logisticians will rely on packaging which performs these basic functions, yet does not generate disposal problems either in a peacetime or wartime environment. Elimination of the packaging provides a significant cost reduction and the elimination of an environmental concern. Future packaging will become more multifunctional with one or more desirable features. Future packaging may become

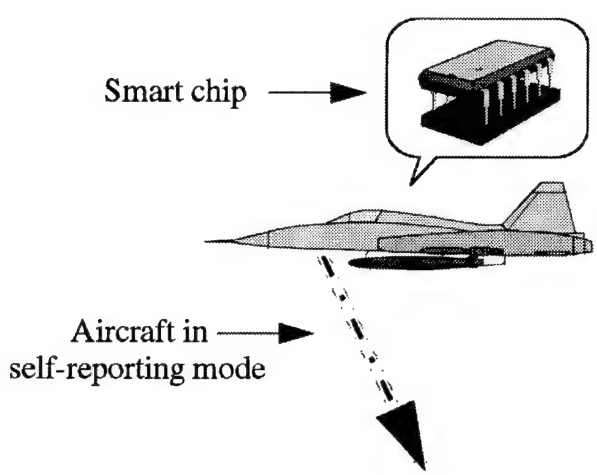

Figure 3-1. Self-Reporting Parts via Smart Chips

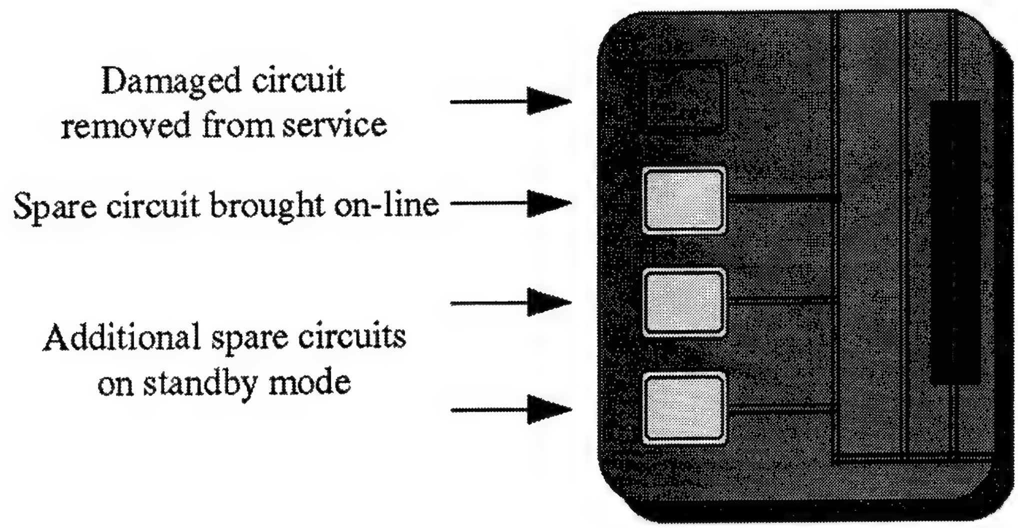

Figure 3-2. Self-Repairing Parts via Rerouting around Damaged Area of Circuit Card

- a fuel when combined with a catalyst;
- edible when combined with a catalyst;
- biodegradable when exposed to water after adding a catalyst;
- multipurpose (for example, internal "foam" or cushion could be remolded to accommodate different components or items—used during retrograde movements); and
- part of the component itself (the package and component form a modular unit which is installed in the weapon system).

Figure 3-3 illustrates two revolutionary options for increasing the usefulness of packaging as highlighted above. By combining the packaging with a catalyst, which could be obtained in the particular theater of operations, a fuel or food is produced.

The heavy reliance on the commercial sector and external drivers for reducing cost will impact the DOD's capability to deliver materiel to engaged units. Forces mobilizing for deployment and units already deployed will move the majority of their materiel by strategic sea lift or by the Civil Reserve Air Fleet (CRAF). These mobility components rely heavily on the use of containerized freight to exploit handling efficiencies and to maximize space utilization. A new Battlefield Delivery System (BDS) will deliver containerized cargo directly to employed forces. The BDS will permit the seamless flow of containerized materiel from point of embarkation, movement by domestic surface carriers (rail or motor carrier), port loading, strategic sea lift, port off-loading, and forward movement by surface or air. Containerization provides several benefits already enjoyed by the commercial sector, including

- reduced handling of packaged goods;
- greatly reduced pilferage and damage;
- standardized equipment available worldwide;
- movement by motor carrier, sea lift, airlift, and rail;
- ease of tracking;
- shipment of almost any good including refrigerated;
- protection from external elements;
- elimination of interior packaging; and
- portable warehousing.

The ability to move containerized materiel provides additional benefits to the military. Containerized freight would

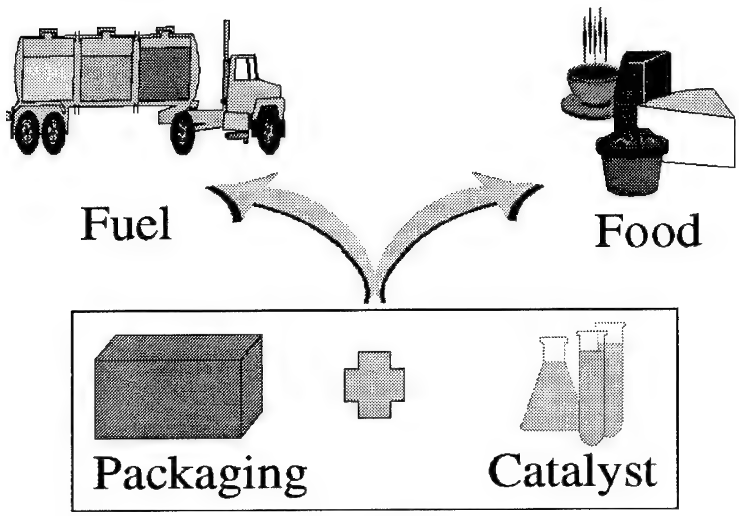

Figure 3-3. Combining Packaging with a Catalyst to Produce Fuel or Food

- be modified to serve as temporary facilities (An entire air base could arrive containerized, fitted with doors, windows, and vents. Once unloaded, containers would become offices, quarters, shelters, and clinics);
- be stored on prepositioned ships until required; and be fitted to include materiel, fuel, food, vehicles, water, or any other items within cubic constraints.

One problem faced by the military is rapid movement of materiel away from the destination port. Arriving containers must move by surface or be unpacked for airlift delivery. Unpacking the containers and loading the airlift adds time, equipment, personnel, and tracking requirements to the pipeline. The BDS will eliminate these requirements by allowing the container to move directly from the commercial supplier to the point of use.

The BDS will operate within the employed theater and will be composed of an air and ground element. The air portion of the BDS will consist of an airlifter in which a standard shipping container, as defined by the International Standards Organization (ISO), would become an integral structure of the fuselage. Figure 3-4 illustrates the concept of the container aircraft. The aircraft consists of three main sections: the cockpit, the wingbox, and the empennage. In its simplest form (short version), the aircraft is capable of flight by joining the cockpit, wingbox, and empennage directly together. With standard shipping containers installed between the cockpit and wingbox, and the wingbox and the empennage, the aircraft would be configured to carry cargo (stretch version). Advanced flight dynamics, mainly in software control for the stability of the aircraft, would control the aircraft's flight characteristics in both the short and stretch versions.

This BDS concept can be jointly applied to the agile base concept, as illustrated in figure 3-5. The first wave of container aircraft to arrive in a theater of operations would be "disassembled." The cockpit would form a command and control facility, the aircraft engines would generate the base's power, the wings would provide fuel storage, and the containers themselves would provide shelter for troops, supplies, and equipment. The containers would integrate with the structure 2025 concept being proposed as a portable base shelter. This concept will provide a mobile base to redeploy as the combat situation dictates.

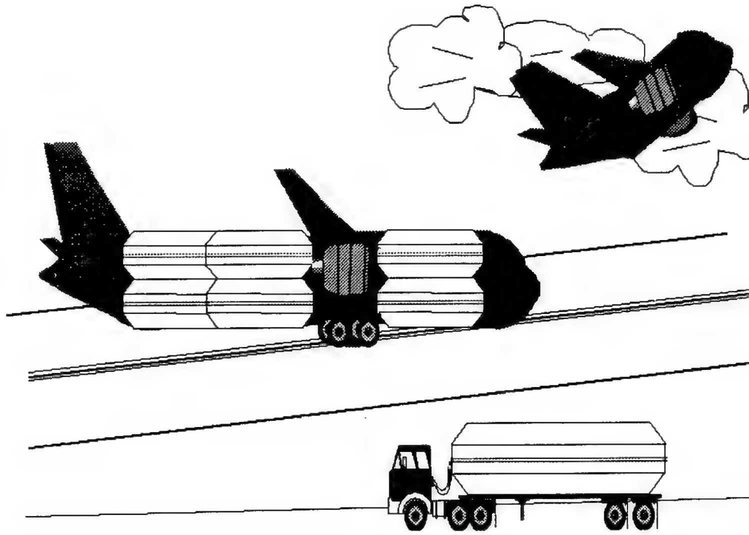

Figure 3-4. Battlefield Delivery System Highlighting the Container Aircraft Concept

The ground portion of the BDS consists of trucks, trailers, and forklifts capable of handling the containers and moving them to staging areas and then to forward deployed units. Development of a truck-trailer with the ability to lift the container without additional material handling equipment will further streamline the process. This concept is defined as demountable loads, in which a vehicle can off-load and pick up its own cargo body bed instead of just its cargo, allowing for rapid vehicle turn-around times. A smaller version of this proposed truck-trailer is currently in use by most western armies.[9]

The BDS will allow the DOD to use commercial carriers for strategic sea lift as well as domestic transportation. The standardized containerized concept allows a seamless movement from source of supply to the battlefield with minimal handling, reduced time, and increased visibility. The

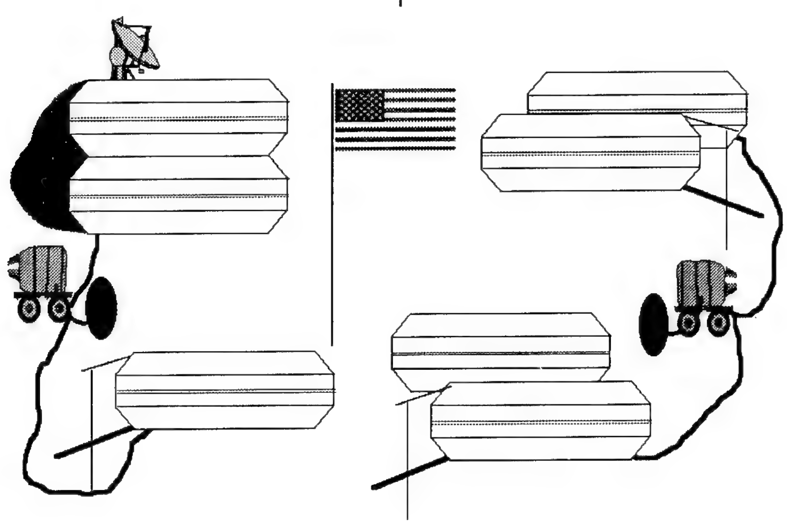

Figure 3-5. Container Aircraft Applied to the Agile Base Concept

BDS provides the same capability whether supporting employed combat forces or providing humanitarian assistance to remote locations. The BDS enables all military services to use any combination of the four pillars of strategic mobility—strategic airlift, strategic sea lift, domestic surface movement, and prepositioning—to move containerized materiel.

Integrating Operations

As D. J. Bowersox and others noted, "The main strength of logistics results from treating system components on an integrated basis . . . . A systems orientation stands in direct contrast to the traditional approach of treating the activities of logistical management on a separate or diffused basis."[10] The cost of supporting complex systems in the future coupled with a constrained resource environment means that logistics systems must be integrated. Stand-alone, service-specific logistics systems will be too costly.

Total Asset Visibility (TAV) is a current initiative being developed by the US Army designed to link all components of the DOD logistics system into a coherent whole using a comprehensive information management and communications system. The goal of TAV is to provide real-time information regarding the quantity, location, and condition of DOD assets anywhere and at any time.[11] The commercial concept of TAV is total supply chain visibility. The difficulties and costs of linking the various information systems operated by the separate military services prevent the goals of TAV from being achieved in the near future; however, the need for logistical excellence and continued rapid advances in information technology in the future will eventually overcome these parochial barriers. TAV will allow the customer to obtain real-time knowledge of the status of any requisition in the logistics system. TAV will serve as a high-tech "hot line" between the customer and the source of supply.

Knowing the status of any requisition in the system and having confidence in the accuracy of that status will eliminate the need for duplicate requisitions and a large buffer stock. In most cases, the requisition will not be initiated by a human worker but will be generated automatically as previously described as self-reporting parts. Instead of maintaining databases on inventory, information systems will conduct a worldwide poll to find status, location, and quantity on an as-needed basis from the battlefield to the commercial supplier. The request for a replacement part will be transmitted to the system node responsible for providing that part, either from inventory or from on-demand manufactures. It is likely that these supply nodes will be vendor-operated and mobile. In all instances, successful logistics support will be the product of advanced information technology, strategic alliances between the government and suppliers, and the flexibility to meet customer needs.

Notes

1. Fedex, http://www.fedex.com/pr/NetShip3_13_96.html, 11 April 1996.
2. A. Braithwaite, and M. Christopher, "Managing the Global Pipeline," *The International Journal of Logistics Management* 2, no. 2 (1991): 55–62.
3. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 31.
4. "New World Vistas" (unpublished draft, the materials volume), 69.
5. *SPACECAST 2020*, vol. 1 (Maxwell AFB, Ala.: Air University, June 1994), K-15.
6. Nicholas Negroponte, *Being Digital* (New York: Vintage Books, 1995), 146, 210.
7. Ibid., 209; also Bill Gates, *The Road Ahead* (New York: Viking, 1995), 9.
8. "New World Vistas" (unpublished draft, the materials volume), 69.
9. P. D. Foxton, *Powering War: Modern Land Force Logistics* (London: Brassey's, 1994), 58.
10. D. J. Bowersox, "The Strategic Benefits of Logistics Alliances," *Harvard Business Review* 68, no. 4 (July–August 1990): 36–45.
11. Deputy Under Secretary of Defense (Logistics), *Total Asset Visibility Conference Program Brochure* (Washington, D.C.: American Defense Preparedness Association, 9 March 1994).

Chapter 4

Changing Processes

In the next 30 years, the processes that are used by logisticians will dramatically change. These changes will be driven by environmental and technological changes, as previously described, but will also result from the implementation of revolutionary new logistics techniques. This section highlights some of the changing processes that will impact logistics in 2025. B. K. Ellram and M. C. Cooper identified the principal question of supply chain management as where in the supply chain to hold inventory. This decision is based on timely, accurate flow of information. "Clearly, exchanging information for inventory is central to the supply chain management concept."[1]

A logistics support system superior to that fielded by the opponent can provide the difference between success and failure. Superior customer service in the military context means the logistics system in place supports requirements determination and forecasting processes that deliver exactly the items required, exactly where and when required. This concept is called dynamic response logistics. The commander of 2025 will provide the what, when, and where information to a logistics system which will rapidly respond to such a request. The future logistics structure will be dominated by a "pull" process rather than the predominate "push" process in use today. However, a combination of the two processes will be employed. Baseline materiel (for common mission requirements) will be pushed while specialized material (for tailored mission requirements) will be pulled.

Materiel Requirements

The materiel acquisition system will change dramatically to meet the needs in the next 30 years. To the extent possible, materiel will be procured on demand with direct delivery to the user by the vendor. Outside contractors will be an integral part of the DOD purchasing system and will have direct access to both consumable and reparables demand information. Visibility into projected requirements provided to vendors through long-term contractual relationships will allow vendors to manufacture and distribute components based on projected requirements, current demand history, and repair capability. Furthermore, commercial carriers will project freight movements based on the manufacturer's projected production date and DOD need dates.

Coordination will entail improved methods of contracting, especially in the use of systems contracting or blanket-order agreements. The trend will be toward fewer suppliers with longer contract periods, rather than contracting on a single-order basis. The contracting function of the future will be expedited, requiring much less daily oversight after the establishment of the initial system between the commercial supplier and the DOD. In connection with increasing the reliance on local purchase, bases will procure with blanket contracts negotiated at a wholesale level, thus avoiding a contracting burden at the local level.

With on-line buying a reality, the contracting officer will receive quotes and place orders rapidly. Where centrally negotiated blanket-order agreements for large numbers of items are arranged, it will be possible for the ultimate user to order directly from the vendor without the intervention of a contracting officer every time an item is ordered. Currently, orders using MILSTRIP are routed to a source of supply which is normally a military inventory control point; in 2025, orders will

be routed directly to a private vendor. Building speed into the logistics system refers to the necessity to translate customer requirements into the completed system or spare parts as swiftly as possible. As product life cycles continue to shrink, the need to combine concurrent engineering with advanced information technology becomes more important. New systems will be built using as much commercial-off-the-shelf and nondevelopmental item equipment as possible.

Further extension of this interface between the commercial supplier and the military will dramatically reduce the need for the current supply structure. Ultimately, there will be no clear distinction between wholesale and retail supply operations, and a fusion of the two systems will occur. Through the process of commercial suppliers using rapid delivery methods to send parts on demand from direct interface with demand information and self-reporting parts information, there will be a decreased number of line items held in inventory. Hence, the holding of inventory at depots will be minimized, dramatically decreasing holding costs. Decreasing inventory will also result in a reduction of the storage and transportation infrastructure at the base level. The days of oversized warehouses, strictly for storing inventory, are quickly passing, and it is likely that the consolidation of warehouses already underway in the mid-1990s will continue.

New information systems will be needed to cope with these changes. Asset visibility of materiel held in stock will remain important even as these stocks disappear, while in-transit visibility requirements will continue to increase. Communication systems will be integrated with those of private carriers and with suppliers to provide the visibility of items required. War plans based on major regional conflicts will result in commercial cargo carriers carrying the bulk of cargo to a hub just outside the conflict zone, with DOD aircraft responsible for hub-to-battle zone movements. The future of transportation, with a greater reliance on vendor-to-user shipments of materiel, will decrease the need to arrange secondary transportation. Hence, the control of secondary transportation will be greatly eliminated. However, this same phenomenon will result in greater tracking difficulties, expanding requirements for in-transit visibility.

Asset Maintenance

The landscape of asset maintenance will dramatically change in the next 30 years. Over the past several decades, the lead time for new weapon systems has become increasingly protracted, due to the increasing complexity of modern weapon systems and the complexities of acquisition procedures. Therefore, weapon systems are likely to change less than supporting technologies and the ways in which those weapon systems are used.

The number of uninhabited aerial weapon system platforms will continue to increase. This feature alone will decrease the number of environmental systems required for aircrew safety. The use of modular components and the extensive use of software-controlled avionics will require maintenance practices that repair software malfunctions. The future maintainer will repair weapon systems using maintenance computers talking to the weapon system computers, rather than using the traditional hardware wrench-turning methods in use today. Improved reliability of a smaller number of weapon systems means that fewer repairs will be necessary. Advances in weapon systems and on-board equipment will undoubtedly continue to become more reliable, thus consuming fewer logistics resources.

Improved maintainability, which has resulted from attention to acquisition logistics, will result in a smaller maintenance burden. Sophisticated test equipment required for modern maintenance will be more mobile. The Multifunction Aerospace Support System (MASS) is one design

currently undergoing evaluation. MASS is envisioned to replicate the functions of nine types of current flight-line support equipment resulting in a substantial reduction in the deployment footprint.[2] By outsourcing repairs to the commercial sector, the base maintenance function will attempt to reduce overhead costs. Therefore, weapon systems will be designed with two-level repair in mind, and remove-and-replace will be the preeminent technique of local repairs. With the advent of self-repairing parts, and self-reporting parts, component maintenance will be radically redefined. Due to the decreasing failure rate of parts, repairs and remanufacturing of failed parts will occur at commercial firms.

The future of depot-level maintenance will be affected by the dwindling number of weapon systems being procured. Decreasing numbers of weapon systems will mean decreasing numbers of systems and subsystems. Required maintenance tasks will affect the viability of the private sector manufacturing base. To keep the remaining contractors alive, repair work will be consigned to private industry at the expense of organic depots. The DOD will be unable to afford the infrastructure of trained personnel, specialized equipment, publications, and data for the relatively small number of repairs that will be accomplished. Increased use of private firms for logistics support will decrease the number of DOD personnel associated with logistics. The DOD annually reports to Congress that at least 250,000 civilian employees are performing commercial-type activities that could be performed by competitively selected private companies.[3]

Self-repairing parts and the evolution of increased reliability will change the nature of the component repair process. No longer will large quantities of parts migrate back to the depot for repair. Instead, the commercial sector will process those parts that fail and require repair or remanufacturing. In wartime, replacement parts will be repaired or manufactured in the theater of operations for a variety of deployed weapon systems through the Mobile Asset Repair Station (MARS). MARS, as illustrated in figure 4-1, is a concept whereby parts can be repaired or manufactured using a mobile facility which can be land-based or water-based in or near the theater of operations, but out of harm's way. The facility features a set of fully-integrated flexible manufacturing

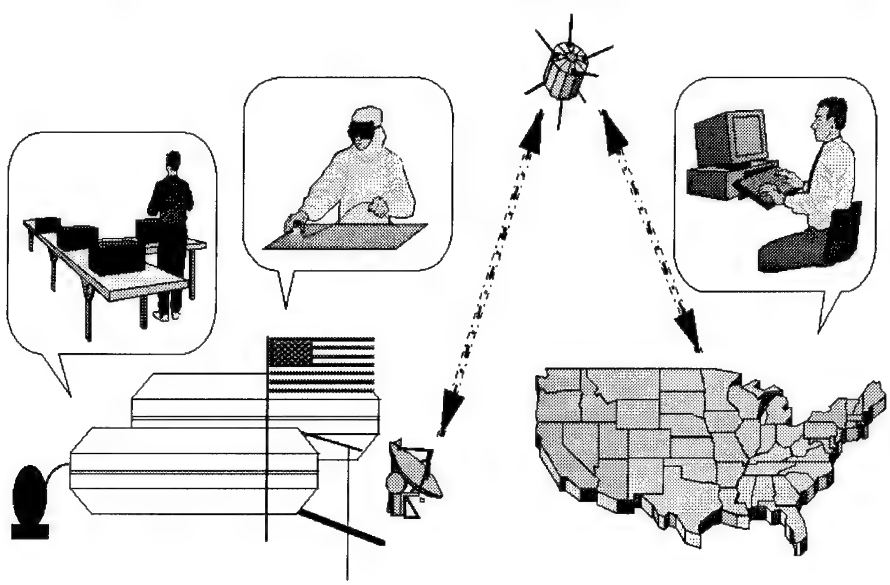

Figure 4-1. Mobile Asset Repair Station (MARS) Concept

systems and robotics systems that are linked to the commercial manufacturers. These manufacturers supply the specifications to the FMS which then produces the part or component. Many of the required materials necessary for MARS to manufacture the components will be obtained from local countries.

MARS will reduce current repair and manufacture turn-around times by days for a number of avionics and mechanical components from a variety of weapon systems. Although the actual logistics tail has not been reduced in length, what flows through the tail has changed. Instead of transporting failed and serviceable avionics and components (atoms), information will be transmitted (bits and bytes).[4] A drawback to "Desert Express," which transported critical reparable parts daily from the US to the Gulf, was that it required a significant allocation of scarce airlift, with two dedicated aircraft and several spare aircraft stationed along the route at various US and European bases.[5]

Financial Management

Financial management systems within the DOD will certainly change in the next 30 years. Future financial management systems will possess three capabilities:

- assignment of direct and indirect costs to specific logistics activities,
- translation of management action into the effect on total costs, and
- integration of logistics financial information with other logistics and financial management systems.

Future cost management systems will require the capability to assign direct and indirect costs to specific logistics functions and subsequently to the product, customer, or weapon system receiving logistic support. Many financial systems already possess the capability to assign direct costs to the activities being performed; however, direct costs will represent a significantly lower proportion of total costs as logistics incorporates more and more technology-based processes.

As direct costs shrink in their relative importance and magnitude, indirect resources will continue to grow in total dollars and management focus. Manufacturing firms have already encountered this phenomenon. Direct labor represented about 85 percent of total costs when traditional cost management systems were designed in the 1920s. However, automation and technology applications have replaced direct labor with many indirect cost functions. Direct costs in many firms today represent only 16 percent of total costs, but the traditional cost systems continue to use direct labor as the principal means for assigning indirect costs.[6]

Currently, using direct costs as an allocation tool creates these challenges for DOD logistics managers.

- Since unit-based allocation suggests costs vary with volume, managers cannot accurately determine how changes in customer service affect total costs.
- There is no reward for reducing indirect cost categories—benefits are diffused across all products.
- Although costs appear to be reduced by eliminating direct labor, they really are not because proportionately the majority of total costs are attributed to indirect costs.
- While overhead costs appear fixed and not affected by management action, in fact, they can be affected through the application of appropriate management practices.
- Rewards, which should be based on cost center performance, become dependent on total product, customer, and channel profitability.

The assignment of indirect costs to logistics activities will require a means for tracing indirect labor and other logistics resources to the activities performed. The tracing of resources provides the total cost of performing individual activities or, by summing activity costs, the costs of different

processes. Future cost management systems will be capable of tracing indirect labor hours, depreciation, training, supervision, data processing, information system costs, and other indirect cost categories to logistics activities.

The resulting activity information will provide significant advantages over conventional cost management systems. Activity-based cost information can

- more accurately determine how changes in logistics service requirements will affect total costs,
- provide ability to trace indirect resources to logistics activities and the cost of their outputs,
- focus on high-cost activities or processes,
- translate logistics performance into cost measures or weapon system availability,
- provide greater visibility over logistics costs—better trade-offs within DOD, and
- simulate changes and impact on logistics costs.

Cost information at the activity level will enable logistics managers to determine the cost per output of each logistics activity as well as the costs of supporting specific weapon systems. The ability to accurately determine activity costs provides the cost information necessary for making smart trade-offs within an integrated logistics system.

Logistics and financial management systems will require significant integration to better support management decision making. Current systems frequently send conflicting signals to DOD managers. These systems use different data to report inventory balances and financial status, do not interface well with one another, and use a large number of interfaces with numerous support systems with inaccurate or "dirty" data. The reports are focused on the expenditure of funds or tracking labor hours rather than on activity costs or management performance. Future systems will use a single database, capable of accepting updates from many users. A single, integrated database will eliminate many of the discrepancies between systems and data inaccuracies. Design of the database and management systems will be developed with supporting management decision making, and not financial reporting, as its principal objective.

Notes

1. B. K. Ellram and M. C. Cooper, "Supply Chain Management, Partnerships, and the Shipper-Third Party Relationship," *The International Journal of Logistics Management* 1, no. 2 (1990): 1–10.

2. E. Boyle, T. Matthew, and Lt Col D. Smoot, "Rethinking Support Equipment," *Air Force Journal of Logistics*, Fall 1995, 28–31.

3. Department of Defense, *Report on the Performance of DoD Commercial Activities* (Washington, D.C.: US Government Printing Office, 30 January 1995), 5.

4. Nicholas Negroponte, *Being Digital* (New York: Vintage Books, 1995), 13.

5. Douglas Menarchik, *Powerlift—Getting to Desert Storm: Strategic Transportation and Strategy in the New World Order* (Westport, Conn.: Praeger 1993), 145–46.

6. Jeffrey G. Miller and Thomas E. Vollman, "The Hidden Factory," *Harvard Business Review*, September–October 1985, 142–50.

Chapter 5

Conclusion

Logistics in 2025 will operate in a vastly different landscape than exists now. Changes affecting logistics will occur in environments, technologies, and processes leading toward the development of dynamic response logistics. Environments will change in the military, business, and logistics sectors. Technologies will change in information technology and systems, packaging and battlefield delivery, and integrating operations. Processes will change in materiel requirements, asset maintenance, and financial management.

These changes will attest to the fact that the dynamic relationships among logistics elements, illustrated in figure 5-1, will reshape the future structures of logistics. These dynamic relationships will be formed through a combination of synergy and balancing activities among logistics elements. Logisticians recognize that numerous trade-offs will occur between logistics processes. Rapid transportation allows for frequent inventory replenishment, thereby lowering inventory levels and reducing the need for fewer and smaller warehouses. Precise delivery of information will reduce the uncertainty associated with inventory and lead to the reduction of safety stocks.

Table 1 lists the evolutionary and revolutionary concepts developed in this study. Logistics operations of the future will operate under an integrated logistics system, or "supply chain management," which will govern logistics decisions and operations. Logisticians of the future will become aware of the entire "bench-to-battle"

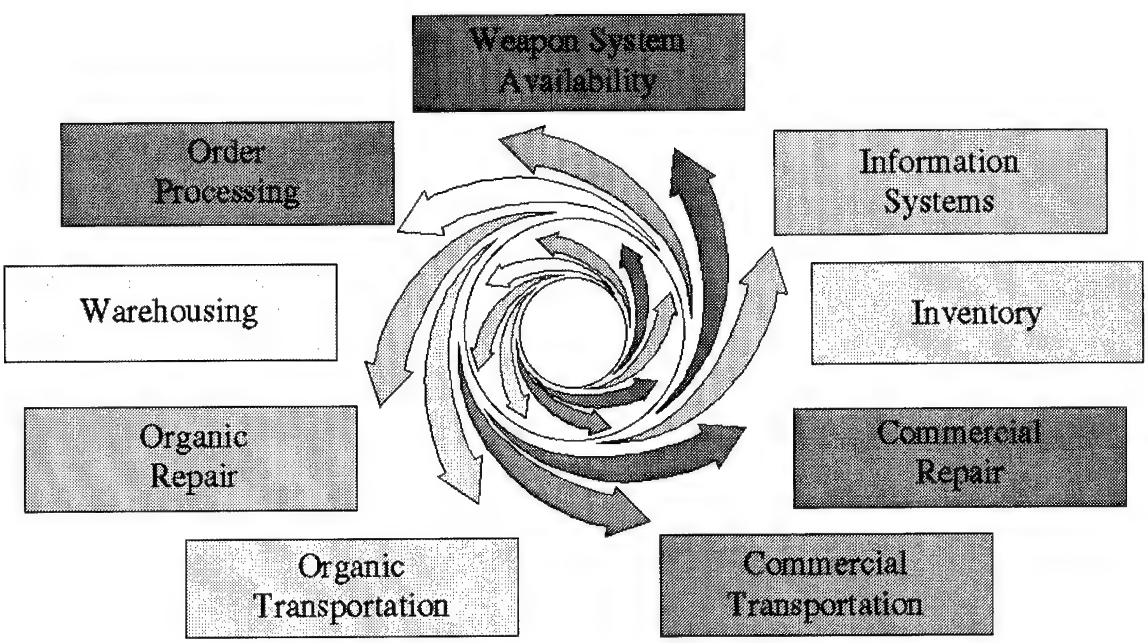

Figure 5-1. Logistics Dynamic Relationships

Table 1
Evolutionary and Revolutionary Concepts

Evolutionary	Revolutionary
• Rapid response logistics	• Self-repairing & -reporting parts
• Privatization & outsourcing	• Multifunctional packaging
• Stronger military & commercial alliances	• Container aircraft
• Complete supply chain visibility	• Wholesale & retail fusion
• Activity-based cost information	• Mobile Asset Repair Station (MARS)

sequence of interactions which will deliver the needed item rapidly and efficiently. Logistics decisions in one area will be made with a recognition of their impact in other areas as well. Increasingly, an awareness of the cost of logistics trade-offs will impact logistics decision making, especially in the notion of trading inventory for information: information is cheap, while inventory is expensive. Future cost management systems capable of accurately assigning costs to logistics activities will permit effective cost trade-offs and reduce total logistics costs while enabling logisticians to target high-cost activities or support processes for reengineering action or privatization.

The revolutionary concepts developed in this study are within US technological capability of the next 30 years. The use of self-repairing and self-reporting parts will greatly reduce both the proverbial logistics "footprint" and decrease the logistics "tail." Multiuse packaging, in which packaging combined with a catalyst produces either a fuel or food product, will reduce the additional shipments of those items into the theater of operations. The BDS with a standard shipping container will provide for a seamless transportation system from the commercial vendor to the theater of operations. The container aircraft will increase the flexibility of the BDS concept and integrate into the agile base concept. The fusion of the wholesale and retail logistics structures will provide for a streamlined flow of goods and equipment and complete supply chain visibility. Logistics will move from a just-in-case system to dynamic response logistics.

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2025 Aerospace Replenishment: The Insidious Force Multiplier

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Executive Summary

Studies examining the future of airpower and space power (such as *New World Vistas* and *SPACECAST 2020*) generally have not revealed much in the area of replenishment. Indeed, there is a noticeable tendency to assume it away with the stated requirement or desire that aircraft should have longer range and loiter capabilities. Even if this were possible, replenishment should be better exploited to mitigate the effect of supporting all or most operations from the United States—a likely prospect in the not too distant future. In addition, some visionaries continue to insist that investment in satellite replenishment is unwise due to the constant need to modernize with new and revolutionary satellite systems. This argument fails to convince when one is open to the possibility that a replenishment platform may also modernize existing satellite systems, thus delaying obsolescence and replacement.

The objective of aerospace replenishment is to provide air and space vehicles with on-demand replenishment. To accomplish this, aerospace replenishment must have the ability to project itself both globally and beyond the earth's atmosphere. It must anticipate customer replenishment needs. Finally, it must have the innate operational responsiveness and flexibility to meet those needs. This paper identifies current vehicles, uninhabited aerial vehicles (UAV), transatmospheric vehicles (TAV), and satellites as potential customers in need of replenishment. Anticipated replenishment supplies will include energy as well as numerous solids, liquids, and gases.

Clearly, the replenishment needs are vast. One platform cannot do all of the tasks well. Therefore, we have identified three types of platforms to meet the specialized needs of customers operating in different environments. A mothership will meet the replenishment needs of UAVs. A multirole automated replenishing system (MARS) will meet the replenishment needs of current vehicles and the TAV. A space support system (SSS), along with space tugs, will support satellites and other vehicles operating in space.

Aerospace replenishment in the year 2025 may be critical in supporting a future presence of US airpower and space power forces. This paper describes the continued applicability of aerospace replenishment and identifies the plausible and credible systems and operational concepts required for the expanded role of aerospace replenishment in the aerospace operations of 2025.

Chapter 1

Introduction

The year is 2025. An economic dispute concerning mining rights between Hendi International, a Khan-based corporation, and Pavin Mining, a US-based multinational corporation, has escalated to the point where tensions now exist between the Khan and US governments. These tensions have increased rapidly and resulted in Khan's veiled threat to use weapons of mass destruction against the US. US intelligence has confirmed the mobilization of Khan personnel and equipment at a remote site capable of launching an attack against the US. The president of the United States has authorized a preemptive strike against this facility. His objective is to neutralize this site within 12 hours.

Unfortunately, the president has a significant problem. In 1996, popular thinking of airpower theorists was centered on designing systems for autonomous global power projection, thereby dismissing the need for replenishing systems. The fashionable image of fast and stealthy platforms captivated these theorists. Unfortunately, engineering and production limitations failed to produce systems capable of independent global power projection by the year 2025. Unable to respond to the crisis before escalation, the US military failed to meet the president's objectives. As a result, US military credibility has suffered a substantial blow.[1]

No one can precisely forecast what the future will hold for the United States and its air and space forces; clearly, however, air and space exploitation will remain important. Over the last 30 years, technological breakthroughs have been successfully exploited to build the strongest and most capable contingent of air and space power that humankind has ever known. Nevertheless, the future is not the time to rest on laurels. In the next 30 years, emerging technology must continually be exploited to build upon the vast capability that exists within air and space forces.

The geopolitical environment of the world requires that the United States continue an active leadership role in world affairs.[2] Although previously up to the task, the United States must hone and maintain its military instrument of power to continue to assert leadership throughout the world. Inherent in this task is the capability to project power globally. In planning for conflicts in 2025, one must assume a diminishing or nonexistent overseas US military presence. Some US military operations may be conducted from bases located within the US and require force projection over large distances.[3] With this type of situation on the horizon, the capability to provide aerospace replenishment to mobility and combat forces will become even more critical in supporting air and space power forces in the year 2025.

Military forces may operate in either the air or space, and only a few will regularly make the transition between the two. Thus, in 2025, the US may have separate air and space forces. The interactions between these forces may be substantial, with space-based surveillance and reconnaissance assets routinely fusing data to air forces. This paper uses the term *aerospace* to refer to the combination of air and space as well as their combined forces. In addition, *replenishment* refers to providing air and space forces with organic essentials such as energy, fuel, and weapons.

Operational doctrine indicates that aerospace replenishment's primary mission is to support other air and space forces. Aerospace replenishment will extend the performance of these assets, enabling

airpower forces to perform longer missions and travel further through replenishment. In addition, aerospace replenishment can save time, money, material, and manpower. Replenishing a weapon system in the air can enable it to arrive over the target or reattack faster. Airborne replenishment can also reduce the ground infrastructure necessary to replenish these combat vehicles. By exploiting weapons replenishment technology, we may enhance performance of the complete weapon system. Space replenishment could extend the useful life cycle of satellites, thereby reducing launch costs and satellite replacement costs. There also is the added benefit of reducing space debris, which results from the growing collection of useless satellites. Eliminating some of the 3,000 tons of man-made debris will reduce the possibility of satellite damage from collisions.[4] Space presents numerous unique challenges; however, this paper limits analysis to satellite replenishment possibilities.[5]

This journey begins with critical assumptions to set the stage for the world of 2025. Following the assumptions, chapter two presents a case for aerospace replenishment—the required capability. The discussion describes the criteria for evaluating various transfer mechanisms and systems. Chapter three uses these criteria to evaluate the methods of transferring these organic essentials. After selecting the candidate mechanisms, the required platforms are described and evaluated. Chapter four presents a concept of operations for the three candidate platforms: the multirole automated replenishing system (MARS), the mothership, and the space support system (SSS). Finally, chapter five provides recommendations on ideas that can lead the US from today towards the world of 2025.

Assumptions

The ***2025*** Alternative Futures study provides the backdrop for this paper.[6] These alternative futures cover a spectrum of possible scenarios and include various assumptions. The following assumptions, either synthesized from the alternative futures study, *New World Vistas*, or developed by this writing team, are the most relevant to this paper's thesis. For purposes of this study, the following assumptions apply:

- US reliance on space-based capabilities will continue to increase.[7]
- Supersonic travel is routine.[8]
- Transatmospheric dimension has been exploited for military application.[9]
- Requirement remains to refuel current aircraft.[10]
- The US must be capable of fighting at large distances from its shores.[11]
- Some operations may be staged directly from the US.[12]
- Bulk of US forces will be based in the US.[13]
- Uninhabited aerial vehicles (UAV) will be a key part of forces.[14]
- Foodstuff and fuel replenishment will extend manned space operations.

Aerospace replenishment in the year 2025 may be critical in supporting a future presence of US airpower and space power forces. This paper describes the continued applicability of aerospace replenishment and identifies the plausible and credible systems and operational concepts required for the expanded role of aerospace replenishment in the aerospace operations of 2025.

Notes

1. Completely fictional scenario tied to ***2025*** Zaibatsu and King Khan Alternative Futures; developed during ***2025*** futures development phase.
2. Joseph S. Nye, Jr., "The Case for Deep Engagement," *Foreign Affairs*, July/August 1995, 90.
3. Air Force Scientific Advisory Board, *New World Vistas*, summary volume (15 December 1995), 5.
4. Col Thomas J. Hall, *Space Debris: A Threat to National Security* (Maxwell AFB, Ala.: Air University Press), 110.
5. The "On-Orbit Support" ***2025*** study white paper writing team provides a detailed investigation of other orbital support operations.

6. The Alternative Futures white paper team provides a detailed description.

7. SAF/CSAF, *Air Force Executive Guidance* (Washington, D.C.: Department of the Air Force, December 1995), 9.

8. Bill Sweetman, "US Supersonic Transport Research Forges Ahead," *Interavia*, January 1995, 20–22.

9. "Space Lift," *SPACECAST 2020*, vol. 1, Air University, Air Education and Training Command, Maxwell AFB, Ala., (June 1994), H-1–H-58.

10. *Air Force Executive Guidance*, 7, 8, 11.

11. *New World Vistas*, 5.

12. Ibid.

13. Jeffrey Record, "The Air War," in *Hollow Victory: A Contrary View of the Gulf War* (McLean, Va.: Brassey's [US], Inc., 1993), 148.

14. *New World Vistas*, 8.

Chapter 2

Required Capability

A revolutionary concept, within the ***2025*** study, would be to put aerospace replenishment out of business.[1] While most future weapon systems may attempt to maximize performance and capabilities, employment of these weapon systems for extended periods of time, at large distances from the US, may require replenishment operations to fully exploit the complete weapon system. As a minimum, replenishment capability within US aerospace forces will increase the effectiveness of military options for future commanders.

Planning for "worst-case" scenarios in 2025 dictates planning for unknown threats in unknown locations. This may entail sustained operations being "executed day and night in all weather."[2] In addition, the US military may be required to have the capability to rapidly project combat forces globally from the US, while employing these forces in synchronized aerospace operations. In the Gulf War, "The bulk of work came from much older systems and mundane technologies such as air refueling (which was required for three-fifths of all combat missions)."[3] Aerospace replenishment forces, as part of the global mobility forces, are required to project and sustain future operations.

Core Competencies

Aerospace replenishment must continue to provide on-demand support and global mobility to the war-fighting commander. These competencies, derived from air refueling core competencies, are built on the concepts of saving time, reducing cost and manpower, and increasing performance—thus providing enhanced flexibility and responsiveness.

The US Air Force demonstrated in Operation Restore Hope that eliminating land-based refueling would increase the on-time delivery rate of cargo to Somalia. Through air refueling, C-5s and C-141s were able to take off with more cargo, thus increasing their cargo-carrying performance. Eliminating the en route staging requirements increased the aircraft's maintenance reliability and reduced the associated manpower costs. Additionally, eliminating en route ground time reduced the time required to arrive at the destination.[4]

The research questions are "how do current core competencies project into future requirements and how are they synthesized into 2025 aerospace operations?" Evolutionary projections of current air refueling capabilities may lead to the development of possible future aerospace replenishment missions. This chapter evaluates possible replenishment media and credible methods of transferring the media between platforms through operational analysis methods. This leads to five potential transfer solutions, which are refined in chapter three.

The aerospace replenishment mission statement for operations in 2025 is to provide on-demand support to air and space vehicles requiring replenishment. Global aerospace mobility and on-demand support are the aerospace replenishment core competencies required to support air and space operations in 2025.

Providing on-demand support to air and space vehicles requires global mobility. US air and space forces must be able to conduct and support aerospace operations throughout the world. Aerospace superiority, the ultimate "high ground," may remain a vital component of future operations. Aerospace replenishment will support aerospace superiority operations by extending the range and endurance of the

combat vehicles carrying out this mission. In the year 2025, control of the air and space above the battlefield may remain a critical factor for our contingency planning efforts. With advances in information technology and information warfare, 2025 war fighters may need to control the "high ground."[5] Thus, space and space systems will become increasingly more essential for effective operations.[6] Much of the military benefit derived from space comes from satellites and the trend is for smaller, lighter, and cheaper designs. One ***2025*** lecturer indicated that some future satellites may be small and light enough to be handheld.[7] During Desert Storm, commanders needed satellites moved to strategic locations to obtain more critical data. Yet using fuel to move satellites shortened the usable life of these satellites.[8] Having the capability to replenish a satellite with fuel will increase the useful life of space systems, thereby enhancing future campaigns. In addition to supporting operations around the world, global mobility involves the capability to reach into space and replenish satellites as well. The mission statement calls for on-demand replenishment. Part of "on-demand replenishment" dictates a global aerospace capability to provide this service. Thus, global aerospace mobility becomes a core competency.

The remaining part of "on-demand replenishment" dictates providing support to the platforms requiring services. On-demand support involves providing the customers what they need, when and where they need it. Global mobility will ensure the "where" part of this equation is attainable. The "what" part of the equation identifies specifically what the receiver platform requires from replenishment operations. By 2025, there may be an opportunity for a weapons replenishment capability in addition to the fuel replenishment capability that exists today. The "when" part of the equation dictates a need for an integrated command and control system capable of coordinating required information to both the replenisher and the receiver. This information system will be capable of providing real-time updates regarding timing and requirements between the various platforms.

On-demand support is comprised of responsiveness and flexibility. The Prussian strategist Count Helmuth von Moltke once said, "No plan survives contact with the enemy."[9] Since aerospace replenishment forces support other aerospace forces, they need to be responsive and flexible. A well-integrated command and control system ensures exploitation of this flexibility. Thus, global aerospace mobility and on-demand support are core competencies in 2025 due to the criticality of aerospace replenishment support during aerospace operations.

Areas for Evaluation

Geopolitical uncertainty about the future dictates that the US must maintain a military force capable of projecting power globally, with the bulk of US forces based primarily in the US. The future warfare tempo may be so rapid that advanced technology weapon systems may be rendered less effective if they cannot deploy in sufficient time to counter global threats. In 2025, a credible aerospace replenishment capability enhances the global employment of US aerospace forces. Traditionally, weapons and propulsion fuel have been the organic essentials required to conduct air operations. In 2025, an aerospace replenishment capability may exist for the following organic essentials:

1. Energy: Laser, directed energy (DE), and kinetic energy (KE) weapons.
2. Solids: Bombs and bullets to KE particles and foodstuffs.
3. Liquids: Jet fuel to hypergolic fuel or chemicals.
4. Gases: Air to plasma.
5. Information.[10]

The next areas to be evaluated are the methods to transfer these materials. A listing

of various systems for transferring these materials follows:

1. Direct: Materials delivered through physical contact.
2. Beaming: Atmospheric energy transfer from source to recipient.[11]
3. Parachute: Lightweight containers that parachute between platforms.[12]
4. Glider: Pods with wings that fly or glide onto platforms.[13]
5. Robotic: Arms that install replenishment supplies onto platforms.[14]

To visualize the feasibility of transferring these materials by the various methods, see the matrix of these materials and methods in table 1. In addition, combinations of transfer methods and transfer materials are scored—on a scale of zero to 10—on the basis of the feasibility of accomplishing the task in 2025. For example, the direct transfer of electric energy rates a "10," the highest possible score, because it is very feasible that aerospace forces could accomplish this transfer. The vertical and horizontal score totals indicate where the overall research should be centered: in the areas of direct transfer of various materials and different methods of transferring electrical energy.

The five highest scoring combinations from this feasibility evaluation are the direct transfers of electrical energy, liquids, and gases, the beaming of electrical energy, and the robotic transfer of solids. The systems description section of the paper evaluates these five combinations. Although limited technology exists to transfer or replenish information, another ***2025*** writing team will address future information replenishment capabilities.[15] While the paper further details these five previously identified combinations, the evaluation must first validate the applicability of the aerospace replenishment of these materials.

To provide measures of merit, this paper identifies the criteria used to evaluate the effectiveness of the transfer and platform systems. Analysis identifies eight prioritized criteria for future transfer systems:

1. Operational benefit: The added capability for the user.
2. Transferability: Ability to accept various media from other platforms.
3. Maintainability: Ease of maintenance and reliability of the platform.
4. Safety: Designed to reduce accidents.
5. Cost effectiveness: Overall cost minimization from cradle to grave.

Table 1
Replenishment Materials and Transfer Methods

TRANSFER METHODS	TRANSFER MATERIALS				TOTALS
	ELECTRIC	SOLIDS	LIQUIDS	GASES	
DIRECT	10	5	10	10	**35**
BEAMING	8	0	0	0	**8**
PARACHUTE	0	4	2	2	**8**
GLIDER	0	3	3	3	**9**
ROBOTIC	7	8	5	5	**25**
TOTALS	**25**	**20**	**20**	**20**	

6. Automation: Reduced human interface during the process.
7. Reload capability: Ability to rapidly reattack or reengage the target.
8. Environment: Concern for the surroundings.

Analysis identifies 10 prioritized criteria for future transfer platforms:

1. Transfer capability: Ability to provide various media to other platforms.
2. Interoperability: Capability to replenish a variety of vehicles.
3. Operating envelope: Capability to operate at varied speeds and altitudes.
4. Survivability: Ability to prevent or avoid destruction.
5. Storage capability: Ability to store large and various energy media.
6. Automation: Reduced human interface during the process.
7. Cost-effectiveness: Overall cost minimization from cradle to grave.
8. Mobility: Worldwide ease of movement.
9. Safety: Designed to reduce accidents.
10. Environment: Concern for the surroundings.

Currently, the only method of aerospace replenishment is the direct transfer of fuel through a boom or drogue. In order to fully evaluate the benefits of replenishment, this paper explores the complete spectrum of materials such as energy, solids, liquids, and gases. Directed-energy power sources such as electrical, gases, and liquids can possibly be transferred; however, the scientific community needs to further explore storage technology to be able to justify the cost of DE power transfer. This stems from the fact that current electrical storage technology is not feasible or economical for DE weapons employment.[16] The development of storage devices should proceed much faster than DE weapons development due to the commercial use of storage technologies. Therefore, by the time DE weapons become operational, storage devices should not be a restriction and the need to transfer energy will remain.

In-flight transfer of solids to include conventional-type weapons (such as bullets and bombs) provides another opportunity to more rapidly employ firepower, thereby overwhelming the enemy's ability to react. Through the use of robotics, it may be feasible to rearm aerospace vehicles with conventional munitions in-flight. A general officer indicated that there was much discussion during past conflicts on the obvious desirability of accomplishing conventional weapons replenishment.[17]

With advanced technology available for flight guidance computers, automated aerospace replenishment technology should be pursued. This feature facilitates a low-visibility aerospace replenishment capability, thereby increasing the effectiveness of our airpower and space power forces. In addition, automated uninhabited replenishment platforms eliminate the need for planning crew rest prior to long operations. These automated vehicles contribute to enhancing the replenishment capability of aerospace forces in 2025.

Based on these required aerospace replenishment capabilities, a multipurpose replenishment system can possibly accomplish the transfer of energy, solids, liquids, and gases. However, multiple platforms are needed to satisfy energy transfer needs within the aerospace environment.

Notes

1. Dr Dennis M. Bushnell, chief scientist, NASA Langley Research Center, ***2025*** Assessor Comment on ***2025*** first draft white paper, February 1996 (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

2. *New World Vistas*, summary volume (15 December 1995), 5.

3. Eliot A. Cohen, "The Mystique of U.S. Airpower," *Foreign Affairs* 73, no. 1 (January/February 1994): 112.

4. Lt Col Yoshio Smith deployed to Moron Air Base, Spain, as the KC-135 Operations Group commander to coordinate air refueling along the Portuguese coast, Mediterranean, and Azores.

5. While the North Vietnamese were able to "hide" against the might of the US air strikes, the future space-based battlefield dominant information system could pinpoint those in hiding against a less technologically endowed opponent. Of course, an opponent with less technology in their warfare could possibly counter the technologically superior opponent.

Perhaps the tempo of warfare may belong to the information-dominant warriors.

6. *New World Vistas*, 11.

7. Guest lecturer, lecture to ***2025*** participants, Air War College, Jones Auditorium, December 1995.

8. Christopher Whitlock, Operations Support Office, National Reconnaissance Office, interview with Lt Col Yoshio Smith, Maxwell AFB, Ala., 26 February 1996.

9. Edward S. Miller, *War Plan Orange* (United States Naval Institute, Annapolis, Md.: Naval Institute Press, 1991), 333.

10. John A. Kennedy, Delta Airlines pilot, during interview with Lt Col Yoshio Smith, 22 March 1996, stated that Delta aircraft can receive air traffic control clearances on a computer display within their cockpit without voice radio transmissions. Other ***2025*** teams are addressing information operations in the aerospace environment.

11. Lt Col Brian L. Jones, chief, ***2025*** Technology Team, interview with Lt Col Yoshio Smith, Maxwell AFB, Ala., 7 February 1996.

12. Dr Wade Adams, ***2025*** Assessor Comment on first draft white paper, February 1996 (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

13. Ibid.

14. Jones, interview with Smith, 7 February 1996.

15. Other white papers in ***2025*** study address information operations.

16. Verbal feedback on the Aerospace Replenishment Team's briefing to the Air Force Scientific Advisory Board, Air University Library, 7 February 1996.

17. Lt Gen Charles T. Robertson, vice commander, Air Mobility Command, comments to Aerospace Replenishment Writing Team, Air Mobility Command video teleconference, 28 February 1996.

Chapter 3

System Description

The previous chapter presented the aerospace replenishment core competencies and identified transfer media and platform characteristics. This chapter analyzes the replenishment mission and explores plausible technologies of 2025. It also marries the scientific capabilities with the mission requirements in order to offer several credible systems for further analysis.

In order to fulfill the required mission capabilities, revolutionary systems are needed. The overall systems include the transfer mechanisms as well as the platforms that are needed to support those mechanisms. The transfer systems are those mechanisms employed to transfer the organic essentials: energy, solids, liquids, and gases.

Transfer Systems

A variety of methods to transfer the energy, solids, liquids, and gases are available. Previously described were four groups of materials and the feasibility of their transfer via individual transfer methods. Individual transfer systems would be inefficient; therefore, an integrated system that can transfer everything may be necessary (e.g., an integrated replenishment boom system).

A key component of the transfer system is a replenishment boom that can accommodate vehicles operating in 2025. In addition to transferring liquid carbon-based fuels, this system can transfer liquids such as hypergolic fuels. Transfer of solids, particles, or gases can be accomplished by modifying the boom to a pressure system where the replenisher selects the amount of pressure required to transfer the different media. Electrical transfer will utilize the same integrated replenishment boom. The insulated conductive material located through the center of the boom facilitates electrical transfer while liquid, gas, or solid transfer occurs outside the conductive core. Therefore, a need exists for a single integrated boom transfer system that can transfer all four media. The following sections explore such a system's feasibility.

Transferring Energy

The capability of directed-energy and kinetic-energy weapons in 2025 will extend beyond the capabilities of today's precision weapons. Already, laser technology has demonstrated the ability to destroy aerospace vehicles.[1] Easily envisioned are UAVs used extensively in the high-threat environment with DE and KE weapons as the standard armament. Will they need an external energy source to sustain operations? UAVs may be powered by small engines and may not have the generator capacity to energize the large capacitors or batteries needed for high-tempo operations.[2] Likewise, the limited carrying capacity will prohibit extensive internal storage devices for the electrical energy or chemicals. Therefore, the energy will need to be transferred from either a ground-, air-, or space-based system, each of which has advantages and disadvantages that must be evaluated (table 2).

The advantages and disadvantages of each system are further analyzed. For example, in a ground-based system, size is relatively uncritical and generating capability is maximized. Safety, generating capability, and cost advantages can be maximized; however, these are countered with mobility disadvantages. Air-based systems can be placed in numerous vehicles; however, the mobility and flexibility of air assets are offset by higher risk, higher operating cost, and lower

Table 2
Energy Transfer Criteria Ratings

WEIGHTED CRITERIA	GROUND BASED	AIR BASED	SPACE BASED	JOINT AIR & GROUND
OPS BENEFIT (20)	16	17	14	19
TRANSFERABILITY (19)	16	15	14	18
MAINTAINABILITY (16)	15	13	8	14
SAFETY (14)	12	10	8	11
COST EFFECTIVENESS (10)	9	8	6	8
AUTOMATION (9)	7	7	8	7
RELOADABILITY (7)	7	6	5	7
ENVIRONMENT (5)	3	3	4	3
TOTAL (100)	**85**	**79**	**67**	**87**

generation capability. Space-based systems to reenergize UAVs have the advantage of constant availability and tremendous "multimission capability."[3] Unfortunately, the disadvantages of using a space-based replenishment system seem overwhelming: high cost, complicated maintenance, and limited generation capability. More important, if space systems had the capability to energize the UAV capacitors, they might independently destroy the targets. The final area for analysis is a joint ground and air system. In this joint system, the generating capacity of the ground system could be used to direct energy to an energy relay system located in-theater. The in-theater air asset could then transfer the energy to a low-altitude UAV (fig 3-1).[4]

Synthesis of the ground and air systems will be vital in 2025. If operations occur near friendly territory, the ground-based system could be deployed with the UAV support system to fulfill energy transfer requirements. During long-range operations and over extended hostile territory, the ground-based system could directly reinforce the generating capability of an aerospace vehicle, which could then replenish the UAV. This energy transfer is necessary if we are to meet the energy requirements of KE or DE weapons.

Directed-energy weapons have great destructive capabilities because a large quantity of energy is transmitted in an extremely short time. A laser system does this by wavelength absorption. For example, a laser system can destroy a target by using thermal methods (infrared) to heat the enemy vehicle's surface in an extremely short period of time. DE weapons can also destroy objects by impulse methods—like a microwave—to blow material off the surface. This damage can be accomplished within a fraction of a second with 200 to 400 joules per square centimeter of energy transferred.[5]

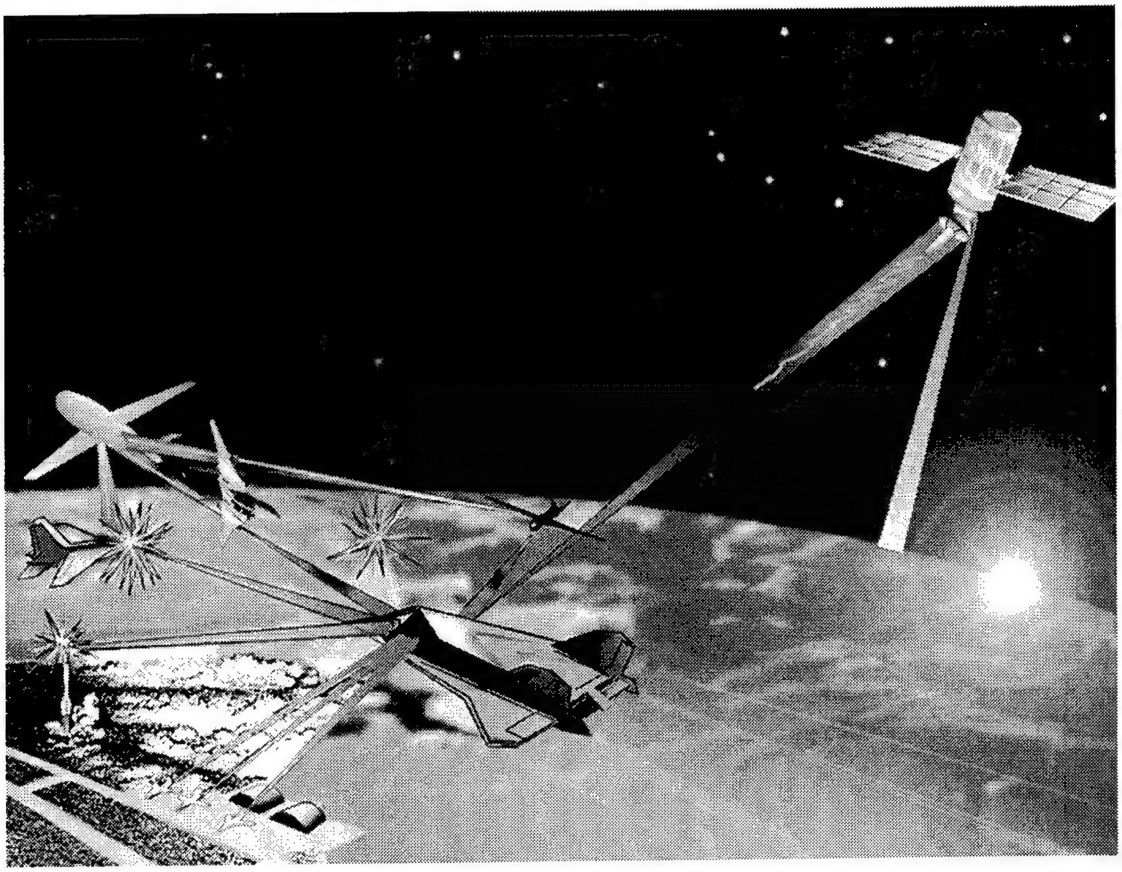

Figure 3-1. Energy Transfer Operations

If the infrared or impulse wavelengths are extended, then nondestructive power transfer is possible.

Electrical energy may be rapidly transferred using lasers or microwave methods. Alternatively, another method of electrical energy transfer is through the collection and transfer of solar energy. For example, a satellite away from atmospheric disturbances can collect solar energy at approximately 140 milliwatts per square centimeter. Converting the sun's destructive rays into visible light makes it possible to beam energy to a lower orbiting satellite's photo-voltaic cells. This process can increase the solar energy collection significantly above the 15 to 18 percent efficiency possible from direct collection by the same low-orbiting satellite. Another solar method is to convert the sun's energy into laser energy. The laser would transmit the energy for absorption to a chemical-type receiver unit that may then turn a hot turbine for propulsion. Well into the future, exotic methods such as the plasma ball concept may become possible. This method projects a space-generated plasma cell (like St. Elmo's fire) onto a receiving unit.[6] The transfer of energy is critical to aerospace replenishment of DE and KE weapons; however, the efficiency of the collection, transfer, and storage of electrical energy requires significant development.

Transferring Solids

Future aerospace campaigns may continue to require massing decisive force in an area and employment of this force on intended targets. If today's trend towards a knowledge-based society continues, the US may develop and procure a highly advanced or "Third Wave" military force. However, the

requirement will remain to fight those forces that counter with an extensive industrial or "Second Wave" military. In this scenario, inflight conventional weapons replenishment contributes to an increased operations tempo. This capability may be necessary for future operations against "First or Second Wave" adversaries. The use of robotics could provide this physical transfer of conventional munitions. Robotics provides a substantial toolbox, including low-cost electronics, servomechanisms, controllers, sensors, and communications equipment.[7] While the transfer of conventional weapons appears possible, it is a small niche in the aerospace replenishment environment. Unfortunately, this small requirement entails large expenditures. Therefore, the use of robotics for in-flight conventional munitions replenishment offers limited force enhancement capability (fig. 3-2).

Kinetic energy and particle gun weapons replenishment can be accomplished through compressed gas or suspension of the particles. Particle transfer systems can employ a mechanism much like that of a BB gun, but with much lower pressure. If the particles are small, then suspension of the kinetic material in a liquid medium like water, oil, or jet fuel will be feasible. Once the transfer of the particles to the receiver is complete, they can be filtered for use in a weapon system. The suspension medium can be dumped overboard, used as an energy source, or simply extracted from the receiver vehicle upon landing.

More radical methods of transferring solids would include the use of parachute or glider operations between the platforms. Despite the fact that C-130s have used parachute recovery methods in the past, parachute operations appear to provide little benefit except to similarly configured cargo

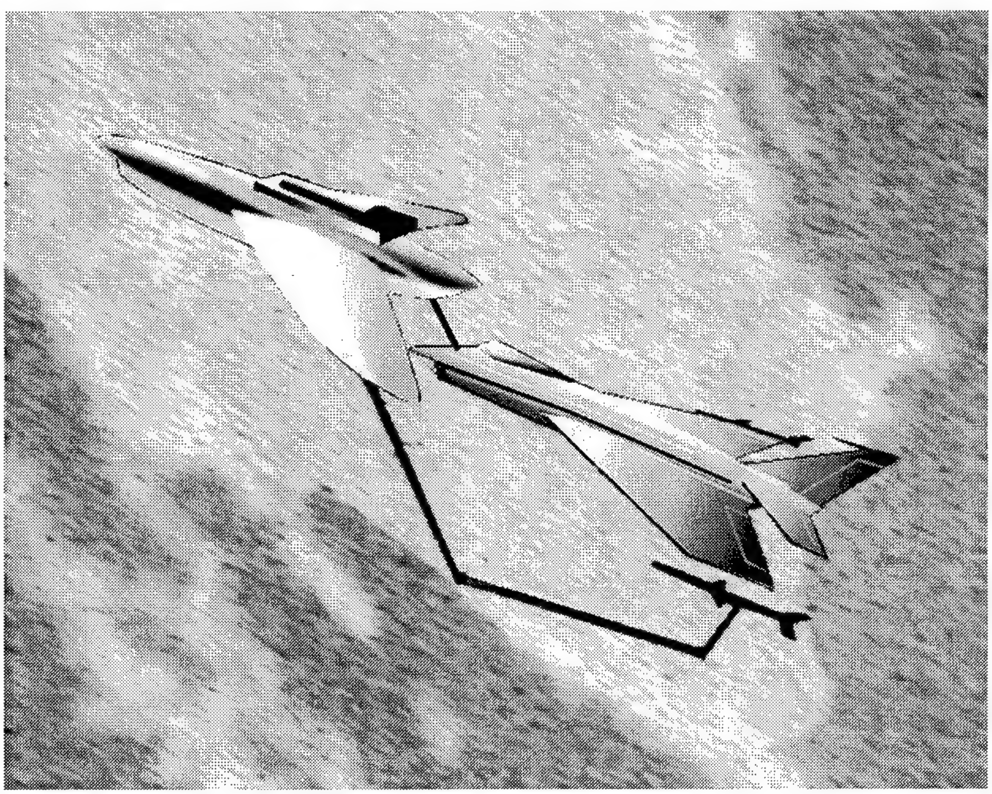

Figure 3-2. Conventional Weapons Transfer Operations

aircraft.[8] Powered glider operations may prove possible for transfer of large external munitions. In this concept, gliders would depart from the ground or another vehicle and maneuver to the receiver vehicle. Once in position, the robotic mechanisms could complete the transfer. Some may consider this a dream but many considered transferring liquids impossible before the "Question Mark."[9]

Transferring Liquids

Future replenishment systems may require the ability to transfer noncarbon-based fuels to propulsion or laser systems. Hydrogen and chlorine-based compounds can be used as light and heat sources. In the propulsion system, the heat energy generated from chemical reactions is converted into thrust.[10] In the laser system, the excited molecules provide the light energy needed for laser weapons.[11] Therefore, a system that can replenish a vehicle with chemicals for propulsion can also replenish the laser system. Political and environmental benefits result from reduced dependence on petroleum. A UAV with the chemicals for a laser system can use the same chemicals for the propulsion system. There will be an employment tradeoff between using the chemicals to remain airborne versus availability of laser-kill shots.[12]

The replenishment systems need to separate liquids for internal use from those designated for transfer. The transfer of these liquids should not present physical problems; however, storage and safety solutions may prove difficult. Advanced liquids may have volatility, corrosion, or other problems. These concerns may force the development of additional systems that are incompatible with the integrated replenishment boom. Safety may also provide a reason for transferring gases.

Transferring Gases

While most gases liquefy for storage and transfer, some may remain gaseous for safety or material purposes. The transfer of these gaseous materials would use the same integrated replenishment boom used for liquid transfers. The chemical processes of these gases may be needed for power, light, or heat. The transfer entails irrigating or purifying the boom with an inert gas and then beginning the transfer. The system could use a positive pressure transfer as previously described in the solids transfer sections. Currently, fuel pumps provide the pressure to transfer fuel. On the future transfer system, pumps will pressurize gaseous transfers.

Table 2 provides feasibility values for each transfer combination. To facilitate systematic evaluation of the five highest-rated transfer combinations, an expanded matrix of the desired characteristics of the various transfer mechanisms is provided in table 3. The numbers following the individual criteria are the maximum scores for that event weighted so that a maximum total score is 100. Weighting these scores emphasizes the customer requirements that lead to operational capability.

These eight characteristics are those deemed vital for aerospace operations in 2025. The highest-rated transfers are the direct transfer of electrical energy and liquids. That current systems are capable of transferring liquids and scoring 89 points indicates that this will continue to be a vital need in 2025. The direct transfer of electrical energy scored an 84, despite having rated average in the heavily weighted categories. The beaming of electrical energy is environmentally risky and relatively unsafe due to the flow of energy through the atmosphere. In addition, this system appears to be costly to both develop and field in the operational world. However, the beaming of energy is vital to the complete direct transfer system. The ability to beam energy from a ground or space station is the enabling technology for high-tempo directed-energy transfer operations. The direct transfer of gases would have scored much better except for its limited operational benefit. If the need for in-flight transfer of gases becomes

Table 3
Transfer Systems Criteria Ratings

WEIGHTED CRITERIA	DIRECT ENERGY	DIRECT LIQUID	DIRECT GASES	BEAMING ENERGY	ROBOTIC SOLIDS
OPS BENEFIT (20)	17	19	15	18	13
TRANSFERABILITY (19)	16	18	18	18	10
MAINTAINABILITY (16)	14	12	12	13	9
SAFETY (14)	10	12	12	9	7
COST EFFECTIVENESS (10)	8	10	9	8	4
AUTOMATION (9)	8	8	8	9	9
RELOAD (7)	7	7	6	6	5
ENVIRONMENT (5)	4	3	3	3	4
TOTAL (100)	**84**	**89**	**83**	**84**	61

necessary, the multipurpose replenishment boom establishes this capability. The robotic transfer of solids scored lowest overall. The dangers of damaging the other vehicle or inadvertently releasing a weapon reduce the operational safety factor. This system appears to be expensive—from development through testing to operational employment. Robotic operations also require the most extensive interface with the platform.

Platforms

Three generic platforms are required to transfer the various energy, solid, liquid, and gaseous mediums. These systems are provided to enable a more coherent concept of operations. These platforms are the MARS, the mothership, and the SSS.

MARS

The multirole automated replenishing system (MARS) supports mobility, combat, and spacelift requirements in the year 2025. The critical concerns for the MARS (fig. 3-3) are the platform and the transfer system.

The MARS must be able to carry palletized cargo and fuel, oxidizer tanks, and electrical energy generation and storage devices. In order to meet these challenges, a composite material must be developed that can be light and strong enough to allow a high payload-to-structure ratio. This vehicle must be able to take off and land in an austere environment, perhaps on unprepared surfaces and using advanced vertical short takeoff or landing technology.[13] Both replenisher and receiver aircraft will be equipped with all computerized equipment necessary to conduct automatic rendezvous and replenishment operations. The computerized uninhabited MARS uses advanced guidance technology throughout all aspects of the replenishment operations.

Automated precision air refueling technology is capable of exploitation. This capability can evolve from current navigation,

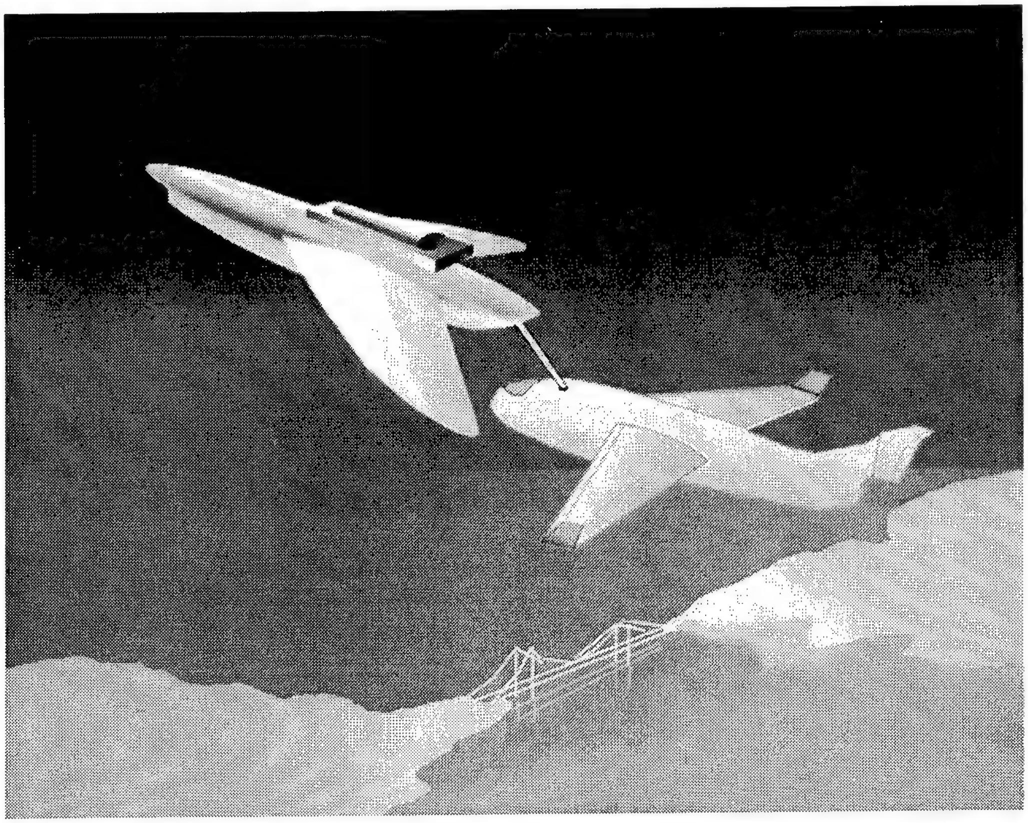

Figure 3-3. MARS Replenishing Transport Aircraft

formation station keeping equipment or SKE, and auto-land systems found on large military and commercial aircraft. Synthesizing this technology into a system capable of accomplishing the mission is the next step. The MARS must have the ability to replenish current vehicles with fuel. In addition, with an integrated replenishment boom, the replenishment of various mediums is possible.

Mothership

The mothership (fig. 3-4) is designed to provide direct combat support to UAVs engaged in delivering precision guided munitions (PGM) or providing combat air patrol.

The mothership is a large wing-type platform used to replenish numerous UAVs with weapons and propulsion power. Kinetic particle and directed-energy replenishment occurs through the docking pods located on the lower surface of the mothership. The mothership has the ability to collect beamed energy, gather solar energy, convert and store solar energy, and transfer the energy through physical means or via beaming. The beamed energy collection antenna is located on the lower surface in order to collect energy transferred from a ground-based system and on the upper surface for aerospace collections. The mothership could possibly serve as the "rearming platform" for the "Fotofighter" described in *New World Vistas.*[14]

The photo-voltaic collection and conversion process requires a revolutionary development to provide the efficiency needed to support high-tempo operations. The photo-voltaic capability of the mothership is adequate during low levels of conflict; however, the need to assist the mothership becomes vital in a high-threat operation. A combination of a

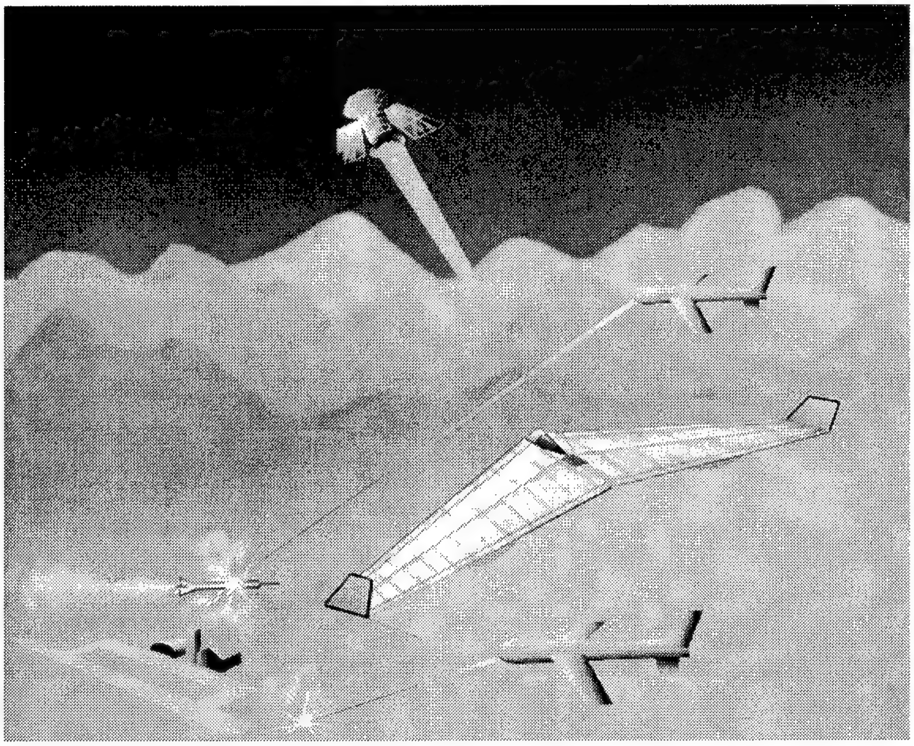

Figure 3-4. Mothership Operations

ground-based and space-based directed energy replenishment system satisfies this need. Storage devices require significant development to reduce the size and weight of the package. We need to develop the ability to target and destroy vehicles with directed energy. At the same time, we need the ability to collect and transfer this energy.

Directed-energy transfer from one platform to another requires accurate tracking. Some developing UAVs operate in the 250- to 350-knot range.[15] While 300 knots is slow relative to the speed of light, it is still fast enough to cause tracking and aerodynamic problems. The UAV's collection panel either deploys from the surface or is an integral part of the UAV skin. If the panel deploys, there is less body interference; however, the mechanics and aerodynamic problems are more challenging. Therefore, a panel that is an integral part of the fuselage may be required.

Technology for the mothership concept will require a minimum of 10 years of serious development.[16] Moreover, synthesis of several technologies will be required to realize this concept. The precision guided rendezvous capability is at least one generation above the current navigation and formation technology. This system will need integration with future navigation equipment to improve the accuracy of the current precision guided tools. The means for energy collection and the transfer of directed energy weapons warrants research. In the command and control environment, limited data fusion technology is available today. With a mothership supporting numerous platforms, data fusion and coordination between these weapon systems becomes critical for successful mission accomplishment.

Analysis of MARS and Mothership

Table 4 presents an objective analysis for comparing the current replenishment systems, the MARS, and the mothership

against 10 weighted criteria. This table addresses the most important criteria for an aerospace replenishment platform in 2025. A grading scale is provided for each criteria, with the key terms for the high and low ratings provided in the "scale" column. A zero is always the low value and the number in parenthesis in the "weighted criteria" column is the weighted high value. The scale provides a weighting, based on customer requirements, for each of the criteria. For example, a perfect transfer capability system rates a 16; a minimally capable system rates a zero. The ideal system would score a total of 100 points. That system is virtually unrealistic, however, due to the contradictory nature of the various criteria. For example, a large storage capability dictates a large platform—which degrades the survivability of that platform. Objective analysis of the data reveals that the mothership appears to provide the most utility for operations in 2025. However, because of the various receiver aircraft or platforms, both the MARS and the mothership are required to fulfill all replenishment needs in 2025.

Space Support System

The need to replenish in space is the basis for development of the SSS. The SSS is a large orbiting platform that can replenish multiple vehicles. The platform's design enables energy collectors to gather solar energy, beamed energy from earth, or beamed energy from other satellites. The SSS is designed to provide space replenishment to orbital vehicles (fig. 3-5).

Table 4
MARS and Mothership Criteria Ratings

WEIGHTED CRITERIA	SCALE		CURRENT SYSTEM	MARS	MOTHERSHIP
TRANSFER CAPABILITY (17)	MULTIPLE	SINGLE	5	12	16
INTEROPERABILITY (14)	HIGH	LOW	5	10	8
OPERATING ENVELOPE (13)	WIDE	SMALL	6	9	7
SURVIVABILITY (12)	HIGH	LOW	3	10	9
STORAGE CAPABILITY (10)	LARGE	SMALL	4	7	9
AUTOMATION (8)	FULLY	MINIMAL	3	8	8
COST EFFECTIVENESS (8)	HIGH	LOW	8	3	5
MOBILITY (7)	HIGH	LOW	7	9	7
SAFETY (6)	SAFE	UNSAFE	6	5	5
ENVIRONMENT (5)	GREEN	BROWN	4	4	5
TOTAL (100)			**51**	**77**	**79**

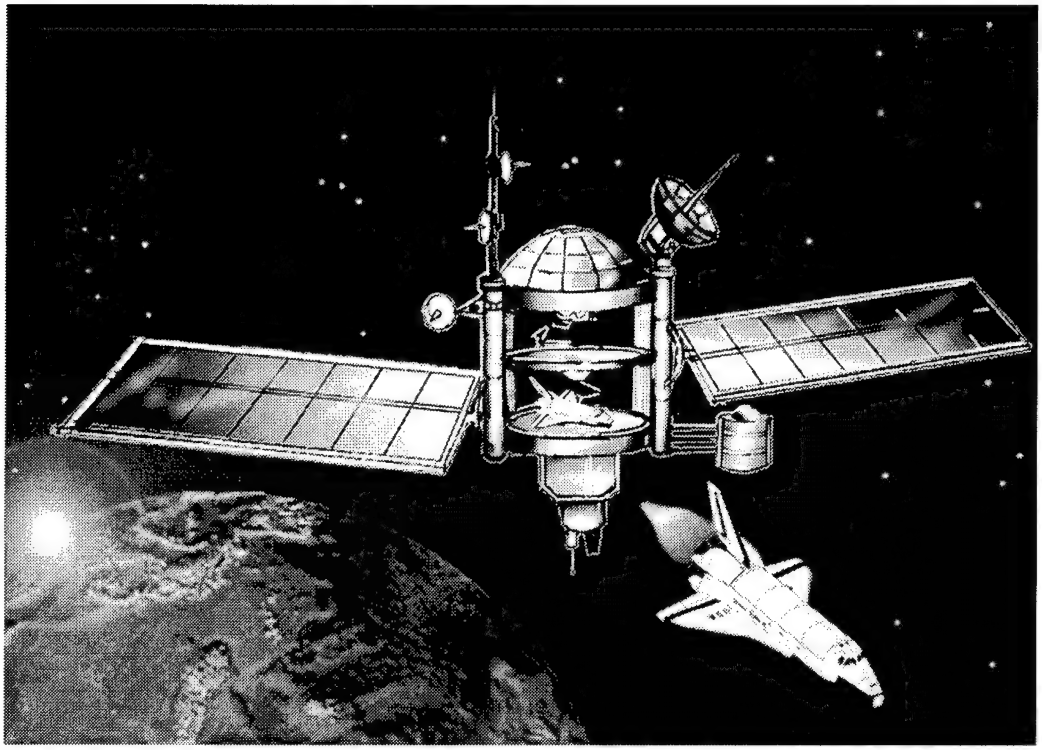

Figure 3-5. Space Support Operations

The multilayered platform increases the "ramp" space used to replenish, modify, and refurbish the vehicles.

The SSS needs to replenish the same media as the MARS and mothership. However, even with the ability to replenish energy, solids, liquids, or gases, the key is to provide fuel to satellites. Propulsion fuel is a limiting factor for space systems because the fuel is used to maintain proper spacecraft orbit or to reposition the spacecraft for mission purposes. Future commanders will have more flexibility to obtain needed data if there is a capability to replenish the satellites.

Two critical issues are the affordability and the purpose of the replenishing system. With dwindling defense dollars, there is a need to keep the satellites in orbit longer. However, cost of launch (currently about $8,000 to $10,000 per pound of payload) must be such that spacecraft replenishment is more cost-effective than launching a new satellite.[17] Historically, satellites are lasting longer than projected. If a fuel replenishing capability existed, satellites could remain in orbit even longer. On the other hand, many satellites become "outdated" soon after they are placed into orbit because of rapid technological advances and ground station enhancements. Costs aside, if satellite design incorporates modular components that are accessible in orbit, then the possibility exists to replenish satellites and upgrade the systems at the same time. Trade-off studies analyzing modular designs for future upgrades versus a new system are continually required.

The SSS is similar to the mothership in that it is a main operating base and other vehicles will provide support.[18] One of these vehicles is the "TUGSAT," a conceptual orbital maneuvering vehicle capable of acting as a space tugboat while repositioning satellites into alternate orbits. The TUGSAT can also be used as a replenisher platform by transferring fuel or energy from the tug to the satellite.[19] Another method of

accomplishing this mission could be through refueling satellites.[20] These systems are capable of carrying satellite fuel such as hydrazine and "Shell Oil 405."[21] Physical contact can be accomplished through a docking device and transfer system similar to the integrated replenishment boom. Robotic arms and hands can then replenish the fuel and install upgrades as necessary, reducing the reluctance to move satellites due to fuel limitations. Satellite-to-satellite refueling will prevent expensive satellites from becoming virtually worthless after their original fuel is depleted.[22]

Another method of satellite energy replenishment is "beaming"—the transfer of energy from the ground to a satellite. The energy beam can provide propulsion for maneuvering the satellite or be used to recharge the electrical systems.[23] This may prove difficult, however, because atmospheric effects make beaming into space much more difficult than from space to earth.[24]

The replenishing satellites and TUGSATs could be permanently stationed in space. The Department of Defense may have difficulty in funding this expensive program on its own, but industry and international communities may be interested in making this a joint global venture. It would seem to be in everyone's best interest to increase the life cycle of all satellites via a transfer from a space replenishment platform.

Supporting space superiority will require the assurance that our satellite force will have the flexibility to contribute to an aerospace campaign no matter where the conflict occurs. In 2025, satellites and space-based weapons could very well be the primary means of force employment during campaigns. The use of an SSS to support space superiority may become critical to assure support for our space-based assets.

Countermeasures

Aerospace replenishment is increasingly viewed by possible adversaries as a "critical soft target."[25] Indeed, aerospace replenishment forces are considered a valuable center of gravity that is an insidious force multiplier. With this in mind, the replenishment platforms need to identify threats at as great a distance as possible—and defend themselves accordingly.

Countermeasures for the replenishing systems evolve from those existing today. Antiaircraft (including DE and KE) weapons are primary threats; secondary threats entail interference and jamming of the onboard systems and data links. In addition, the systems must withstand electromagnetic pulse (EMP) and other possible disturbances.

These countermeasures can be passively mitigated by deploying the systems outside the effective range of enemy threats, deploying computer security measures, encrypting data signals, EMP hardening, and employing stealth technology. Active counter-countermeasures include the use of onboard or escort DE or KE weapons to destroy the threats, since protection against DE or KE weapons appears to be cost-prohibitive. To prevent the destruction of the MARS or the mothership, aerospace forces must be capable of destroying the enemy KE and DE weapons prior to their firing. Due to the high value of the replenishment assets, employment of all passive countercountermeasures and escorts should be included in the mothership mission package.

The *New World Vistas* study recommended a directed energy self-defense system for air mobility aircraft.[26] The key component of this system will be a laser (or high-powered microwave) system that can be fired to defend the air mobility vehicle. This will provide the vehicles the ability to defeat advanced surface-to-air and air-launched missiles. There must also be included in the system a means to provide missile warning, a dedicated high-performance computer to predict the incoming missile's trajectory, and to establish fire control data for the directed energy device. Such a small, energy-frugal system is estimated to weigh less than 500 pounds, be packaged in a 3' x 2' x 2' space, and be deployable internally or in a pod. Prime power requirements for the very

short-duration laser firing should be less than 150 kilowatts.[27]

With the future trend leaning towards uninhabited combat operations, survivability and safety of employed platforms becomes an economic issue, rather than a human issue. Combat planners have greater flexibility when using uninhabited platforms—and combat operations are enhanced when replenishment platforms are employed closer to the battlefield.

Notes

1. Steven Watkins, "Service Closes in on an Airborne Laser," *Air Force Times*, 21 August 1995, 102.
2. Darrell Spreen, director, ABL Technology Office, Lasers & Imaging Directorate, Phillips Laboratory, telephone interview with Lt Col Yoshio Smith, 21 February 1996.
3. Spreen, ***2025*** Assessor comment on first draft white paper (Maxwell AFB, Ala.: Air War College/***2025***, February 1996).
4. *New World Vistas*, summary vol. (15 December 1995), 41. Modified photo to reflect beamed energy from a ground source.
5. Darrell Spreen, telephone interview with Lt Col Yoshio Smith, 20 March 1996.
6. Ibid. Spreen provided the information on solar energy collection, laser transfer, and the plasma ball concept. St. Elmo's fire is a static electricity discharge that can take the form of a "fire" ball.
7. Joseph F. Engleberger, "Robotics in the 21st Century," *Scientific American*, September 1995, 132.
8. Lt Col William P. Stewart, Jr., Air War College student with extensive C-130 pilot operational experience, interview with Lt Col Yoshio Smith, 7 April 1996. He stated that recovering satellites using parachutes has not been done since the mid-1980s out of Hawaii.
9. Office of the Historian, *Seventy Years of Strategic Air Refueling, 1918–1988, A Chronology* (Offutt AFB, Nebr.: Headquarters Strategic Air Command), 2–3.
10. Spreen, 21 February 1996.
11. Ibid. The equation for the chemical reaction is $H_2O_2 + Cl_2 \rightarrow HCl + O_2^*$. The excited form of oxygen, O_2^*, provides the light and by-products in the form of common salts and heat exhaust in the form of water and oxygen. Only 25 percent of the energy is mustered in the form of light; the remaining 75 percent is in the form of heat exhaust.
12. Ibid.
13. Stanley W. Kandebo, "Lockheed, Pratt Test ASTOVOL Concept," *Aviation Week & Space Technology*, 6 March 1995, 48.
14. *New World Vistas*, summary vol., 15 December 1995.
15. David A. Fulghum, "International Market Eyes Endurance UAVs," *Aviation Week & Space Technology*, 10 July 1995, 43.
16. Anonymous Assessor comment on ***2025*** first draft white paper, (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
17. Dr Dennis M. Bushnell, ***2025*** Assessor comment on second draft white paper (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
18. Primary concern from a technological point of view is the affordability of space station technologies. A detailed investigation of orbital and long-term space exploration technologies is also required; however, as an alternative to the more expensive spacelift operations, the SSS may become attractive. The energy collection and transfer technologies available in space should be explored to exploit this concept. The ability to extend operations in the atmosphere is even more important in space due to the high launch costs. Exploiting this enhancement is the primary purpose of the SSS.
19. ***2025*** Concept no. 200150, "TUGSAT," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
20. Concept submission number 200209, "Refueling Satellite," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
21. Lt Col Phillip B. Fitzjarrell, AWC student with extensive missile operations experience, interview with Lt Col Yoshio Smith, 27 February 1996.
22. Concept submission number 200123, "Satellite to Satellite Refueling," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
23. Spreen, ***2025*** Assessor Comment on first draft white paper (Maxwell AFB, Ala.: Air War College/***2025***, 1996).
24. Lt Col Jess Sponable, PL/VT-X, Phillips Labs, interview with the Aerospace Replenishment Writing Team, Maxwell AFB, Ala., 6 March 1996.
25. Tony Mason, *The Era of Differential Air Power* (McLean, Va.: Brassey's Inc., 1994), 242.
26. *New World Vistas*, summary vol., 33.
27. Ibid.

Chapter 4

Concept Of Operations

Today, laser weapons demonstrations have been carried out on the airborne laser system aboard a Boeing 747 where over 200 kill shots can be fired.[1] In 2025 these operations will be carried out by much smaller and less vulnerable platforms. Determining how to employ these weapon systems is vital.

General Operations

The aerospace replenishment platforms of the year 2025 will have the capability to replenish nearly all propulsion and weapon systems. All US aerospace platforms capable of receiver replenishment will have standard replenishment systems. This receiver replenishment system will have an integrated receptacle for simultaneous fuel, energy, and weapons replenishment. Each platform will maximize its value to future aerospace operations through multirole capabilities.

MARS Operations

In the year 2025 aerospace replenishment operations will still require a platform-to-platform physical transfer of energy and weapons. An improvement in operations will be the capability to conduct these operations simultaneously and automatically. The MARS provides a flexible platform that is capable of operating in a variety of environments. The MARS provides rapid replenishment support to combat, mobility, and spacelift forces. In addition, the MARS will have the capability to replenish itself from other replenishing platforms. The uninhabited MARS is controlled by a UAV controller operating in a control room located at the main operating base or in a control pallet aboard a C-17 or future airlifter.

The MARS will be US-based, with a lean logistical structure supporting global deployments and operational missions. Integrated unit deployment of the MARS logistical structure will support autonomous operations on a global scale. If we are required to conduct operations at great distance from the actual battlefield, we must obtain forward operating bases to support MARS operations. With forward operating bases, the MARS will be capable of off-loading a large amount of weapons and fuel. Operations from the US provide unique challenges for replenishment operations, but the MARS platform must be designed to operate effectively in this "worst case" situation.

Most of the airlift fleet will require replenishment at the same geographic point when undertaking a large mobility operation. If this point is outside the support range of US replenishment assets, it will be necessary to obtain a forward operating base for MARS operations. The MARS will have the capability to replenish various mobility platforms. Once a MARS has expended the fuel set aside for replenishment, it will return to base and a fully replenished MARS will take its place.

Ideally, aerospace replenishment anchor areas will be set as close to the battle as possible. This will require replenishment platforms to be equipped with package assets for defense. Each replenishment platform will be assigned to an anchor area for a specified period of time. When a combat platform requires replenishment, it will set a predetermined channel into the auto replenishing mode of the flight data computer. This will enable the receiver aircraft to automatically identify its replenisher, proceed to it, conduct the closure, and commence replenishment operations.

Strict preflight coordination will be necessary for future mobility replenishment operations. The strategic airlift mission must let the replenisher know precisely where and when they need replenishment and how much transfer they require. This is possible through secure command and control channels during the mission-planning phase. This information will be fused into the replenishment platform's internal flight computer. The internal flight computer will be connected to the global command and control system, which will provide the capability for flight planning based on real time and forecast weather conditions.

If diplomatic conditions are positive, a main operating base should be established as close to the replenishment control point as possible. This will enable use of the "air bridge" concept to support the mobility operations. Once a tasking has been received, required information is put into the flight data computer. Based on input data and weather conditions, a flight plan will be produced. This will provide required transfer information and takeoff time. The flight plan, codes for the auto rendezvous and auto air refueling, and transfer data will be transmitted to the aerospace replenisher during preflight operations. After takeoff, the platform proceeds on its planned route while the controller flight follows the aircraft. Rendezvous, rejoin, hookup, and transfer will be automatically conducted.

MARS spacelift replenishment operations allow a TAV to take off with less fuel and oxidizer, thereby enabling added lift capability.[2] The MARS provides TAVs with a fuel or oxidizer top-off subsequent to their entering into orbit (fig. 4-1).[3] Preflight coordination is necessary to provide the required on-demand support. Each TAV will

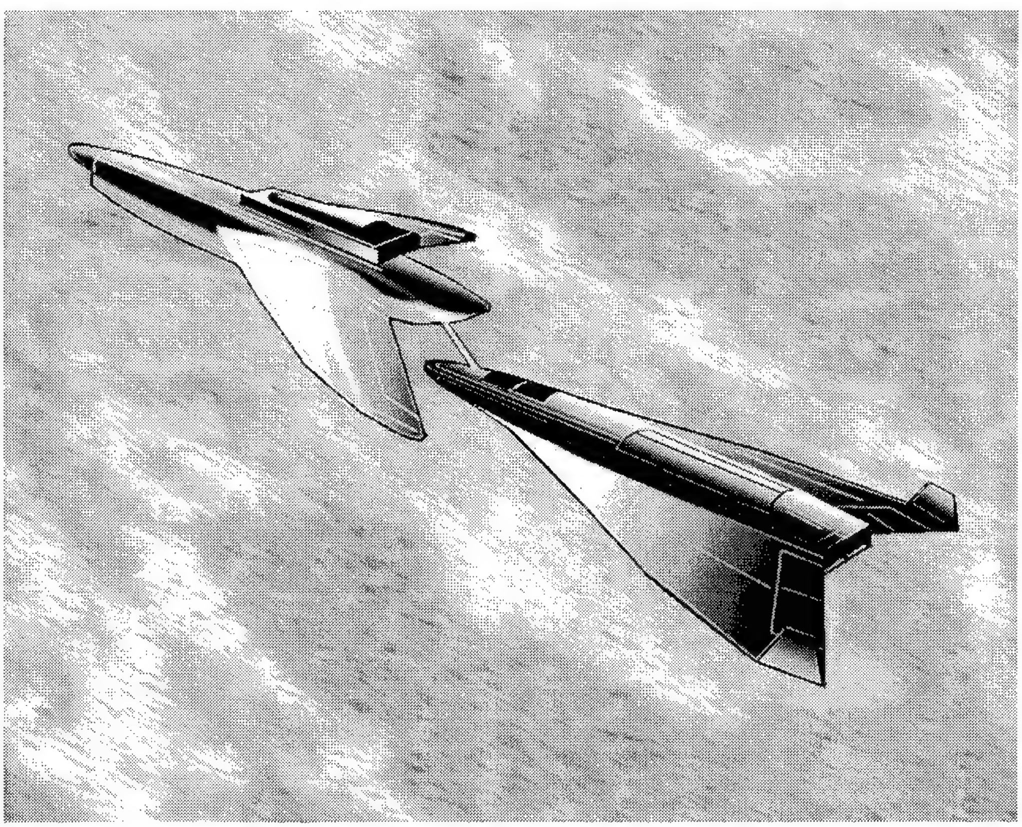

Figure 4-1. MARS Replenishing TAV

be assigned a dedicated MARS for each mission. Once a TAV is replenished, the MARS will return to base or replenish from another MARS and await a follow-on mission.

A primary communication factor in the development of the MARS is its interface with the TAV. The MARS operations must be highly coordinated efforts, much like the cold war SR-71 operations. It will lose a significant mission capability if rendezvous and replenishment are not timely. Thus, a single agency must coordinate the command and control efforts.

The MARS will enhance the capabilities of current aircraft that remain operational in 2025. In addition, it will be the only platform capable of replenishing all future vehicles. Replenishment transfer will satisfy the energy, solid, liquid, and gas requirements of tomorrow's vehicles. As the United States expands into space, the MARS allows each TAV to carry a larger payload. The benefits to space travel will be as great as the mothership's benefits to UAVs.

Mothership Operations

The mothership provides a unique opportunity to project lethal power globally, while operating from the continental United States (CONUS). The mothership requires support from a ground- or aerospace-based system capable of supplying energy replenishment to recharge the mothership's batteries or capacitors. The mothership, with numerous UAVs attached, deploys from a CONUS base and, through the use of beamed energy replenishment, proceeds to any point on the globe (fig. 4-2).

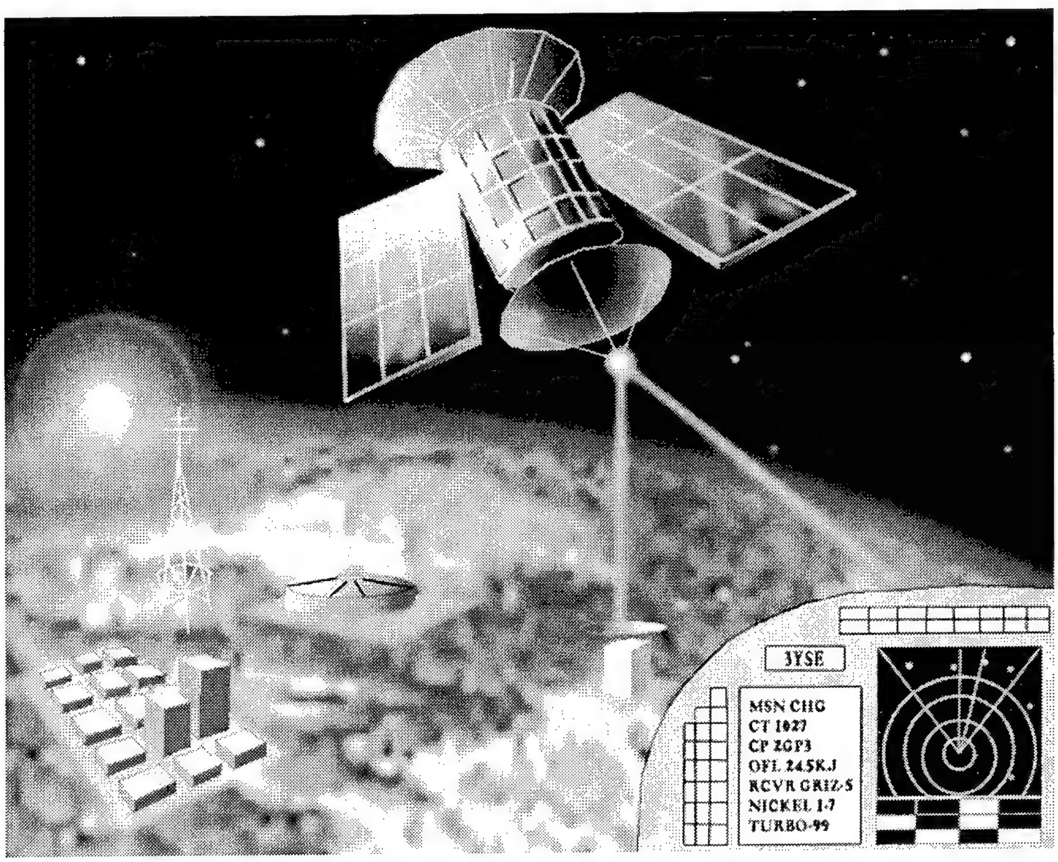

Figure 4-2. Energy Beaming Operations

As the mothership proceeds on its mission, energy beaming occurs from a ground station or satellite to the mothership, recharging its batteries and capacitors. This beamed energy will be used for propulsion and to replenish the UAVs. The mothership has the capacity required for extended endurance because it is uninhabited and can obtain an abundant supply of beamed energy. In a combat scenario, the mothership will proceed to a specific geographic point and begin loiter operations.

The UAVs will deploy from the mothership and proceed to their preprogrammed targets. Once the UAVs have expended their weapons, they will proceed back to the mothership. Upon return, the UAVs will dock with the mothership and begin replenishment operations. The mothership will provide UAVs with energy and weapons replenishment. When replenishment operations are complete, the UAVs can be reprogrammed for a follow-on mission or remain in the replenishment dock awaiting further instructions. Once force employment operations are complete, the mothership will return to its home base. The capability to globally project this type of sustained lethal power offers future commanders a wide array of force application options and adds a credible psychological threat to any future adversaries.

The mothership will be controlled in a manner similar to that of MARS. It will be fully programmable and will be controlled by a UAV controller in a control room. The control room will integrate all UAVs involved in air operations, thus ensuring centralized control. The mothership will be an integral part of any planned offensive UAV operation; its employment should be centrally controlled and integrated into the operations plan.

Although the mothership is a replenisher, there will be times when it receives replenishment. During energy transfer operations, a ground- or aerospace-based generation device could generate significant amounts of energy. This energy could then be transferred to the mothership for storage and later transferred to a combat platform. The ground portion of the system should be mobile so that the system is not subject to a fixed-object attack.

Mothership operations can greatly enhance the capability of UAV operations, but future commanders must have operational control of the mothership and the UAVs if they are to be used effectively. A key element in extended-duration mothership operations is the use of space-based energy replenishment. This replenishment is gained through the integration of the mothership and the space support system.

Space Support System Operations

The SSS mainly supports space power projection. Employment of this system will take many years, and close coordination with NASA experts will be required. The SSS will allow for replenishment of reconnaissance, power projection, and space superiority satellites. Key to this operational concept is that the SSS uses other vehicles to conduct the individual replenishments. These replenishment stations will allow the space-based assets to fully utilize their potential while diminishing the need for spacelift support.

The SSS can be placed both in low and high earth orbits to support space-based operations. Enough systems must be deployed in orbit to ensure adequate and timely coverage of most satellites. The TUGSATs will be used to either reposition satellites or replenish satellites with maneuvering fuel. Once a requirement is identified, a TUGSAT will depart the SSS, proceed to the identified satellite, and facilitate repositioning or replenishment operations. In addition, energy beaming operations, similar to the mothership operation, can be employed.

The complete replenishment system (consisting of the MARS, mothership, and SSS) has a variety of development options, from transfer system to platform. Direct transfer of liquids and energy appears to be the most valuable. A single platform to

replenish everything would be ideal. Unfortunately, due to numerous concerns, from cost to safety, this is not practical. Therefore, a system comprised of MARS, mothership, and SSS will be required for expanded replenishment in the aerospace operations of 2025.

Notes

1. Steven Watkins, "Service Closes in on an Airborne Laser," *Air Force Times*, 21 August 1995, 102.

2. "Space Lift," *SPACECAST 2020*, vol. 1, H-1.

3. Ibid. MARS provides replenishment support at approximately 40,000 feet and 0.9 Mach.

Chapter 5

Investigative Recommendations

Probably to a greater extent than any other future concept, aerospace replenishment planning must be accomplished in concert with receiver platforms. Any system developed to enhance future replenishment operations must be synthesized with the needs and physical capabilities of the receiver platforms and their concept of operations. Developing the MARS and mothership will be of little value unless other platforms have the physical capability to accept the specific replenishment medium. The following prioritized list of required improvements needs integration into a future concept of operations.

1. One standard military system for replenishment operations. Presently, US naval aircraft use a probe and drogue for refueling operations while USAF forces use a boom. In 2025 a standardized replenishment system will be required for all joint forces.
2. To increase the effectiveness of combat platforms, research in energy transfer technology is needed. While the future shows many attractive alternatives, systems costs and funding levels will dictate the aggressiveness of development programs.
3. Replenish energy and weapons as well as fuel. If replenishment operations are expanded to include energy and weapons, the tempo and intensity of air campaigns can be greatly accelerated.
4. Capability to support global operations from the US. Present operations require forward staging bases to support operations far from the US. The battlefield of the future may be dynamic, and it may require the massing of decisive airpower over any point on the globe. These operations may be short in duration and may require replenishment to enhance combat operations. Replenishment platforms with extended range and loiter time demand investigation.
5. Computerized rendezvous and replenishment system to enhance operations, especially under inclement weather conditions. Low-visibility replenishment operations will be required to support aerospace operations in 2025.
6. Capability to employ replenishers with defensive capability in hostile airspace. Presently, air refueling platforms have no defensive capability. To enhance combat operations, replenishment vehicles will be deployed in hostile airspace. Some type of self-defense capability will increase the survivability of the replenishment platforms.
7. Increase the operational replenishment envelope. Ideally, replenishment forces should meet and service customers anywhere, and at any speed, throughout the aerospace regime. Unfortunately, the propulsion systems required to lift and support operations at high altitudes and high speeds are extremely expensive.
8. Replenish multiple receivers at the same time and at a faster rate. A limiting factor for planning purposes is cycle time on the boom or drogue. If the capability to quickly replenish receivers is pursued, a synergistic effect can be felt throughout the air campaign.

With the implementation of these recommendations, a fully integrated aerospace system will enable the expanded role of aerospace replenishment for aerospace operations of 2025. The thesis of this paper was to describe the continued applicability of aerospace replenishment and identify the plausible and credible systems and operational concepts required for the expanded role of replenishment in the aerospace operations of 2025. The capability required to conduct operations

throughout the world is the starting point in proving the continued applicability of aerospace replenishment. Numerous transfer methods were presented; however, the research emphasis should hinge on the direct transfer of liquids and energy and on the beaming of energy. These transfer methods are valid throughout the entire replenishment spectrum. Unfortunately, a single vehicle is incapable of fulfilling the replenishment mission. Therefore, the development of MARS, mothership, and SSS is warranted. With these advancements, aerospace replenishment can be the insidious force multiplier of 2025 and beyond.

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Airlift 2025: The First with the Most

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Maj Michael F. Welch

Executive Summary

Power projection is critically dependent on mobility forces. The air mobility system should be capable of supporting national objectives from humanitarian, nonhostile operations through armed conflict. Because of operational constraints that include evolving threats and reduced external infrastructure, the airlift system in the year 2025 should be independent of theater-basing structure. International political changes will likely necessitate the basing of most, if not all, US military forces in the continental United States (CONUS). However, this will not end the requirement for a global US presence. Although the probability of direct foreign military threats to our interests may be slight, Air Mobility Command (AMC), the air transportation arm of US Transportation Command, must be prepared to conduct global air mobility on a daily basis. In addition, AMC must continue to support humanitarian and peacekeeping missions in both benign and hostile environments. These expanding requirements demand attention. This paper proposes technologically feasible concepts to meet the air mobility requirements posed by probable US national objectives in the year 2025. The employment and integration of technologies that exist today, along with those that will develop by the year 2025, will allow the concepts proposed in this paper to meet future needs.

A number of assumptions were made to narrow the focus of this paper. First, the recommendations herein assume no traditional intratheater airlift capability. This assumption addresses a worst case scenario and drives our requirement of direct delivery from CONUS to the war fighter. A corollary to this assumption is the belief that the availability of overseas basing will continue to decline, thus necessitating long unrefueled ranges, limited materiel on ground, and the decreased utility of Civil Reserve Air Fleet (CRAF) assets. Secondly, this paper assumes that any lift capability extraneous to traditional air-breathing platforms is the purview of other ***2025*** projects. Therefore, our primary concern with other lift assets is the intermodality and interoperability between systems in an overarching logistics framework.

Considering technologies that should be available in the year 2025, several possible systems are evaluated for their applicability and usefulness to the airlift mission. Of these, a combination of large airships and both powered and unpowered unmanned aerial vehicle (UAV) delivery platforms appear to provide the greatest utility.[1] This system, operating in conjunction with existing airframes, will use a greatly improved command, control, communications, computers, and intelligence (C^4I) system to provide clear and continuous command and control as well as direct communication with the customer. In-transit visibility will provide the user/war fighter invaluable insight and enhance his operational capability. Communication with the user/war fighter will also provide for the delivery of

personnel and equipment directly where needed within 10 meters of the target. System costs will adversely affect the development of any new system; therefore, the Air Force will be required to depend on research, development, and production in the civil sector.

Note

1. Throughout this paper the term "unmanned" will be used vice "uninhabited." For our purposes, vehicles are unmanned.

Chapter 1

Introduction

No matter how good the armed forces are, they are of no value if they cannot be in the right place at the right time and in the right numbers to get results.

—Adm James R. Hogg, USN
"Reinforcing Crisis Areas"

The single biggest deficiency in the Department of Defense is lift.

—Gen Ronald R. Fogleman, CSAF
Address to ***2025*** Participants

With the successful end of the cold war and the achievements of Operation Desert Storm, the United States armed forces find themselves firmly established as the world's preeminent military force. These successes have led to an increased willingness by the national command authorities (NCA) to deploy forces throughout the world to meet national objectives. Plausible future scenarios indicate an increase in this tendency for involvement.[1] A dilemma exists, however, and threatens to undermine America's military strength even while the evidence of that strength is undeniable. That dilemma is air mobility. The current air mobility system will not support the air logistics requirements we are likely to face in 2025.

This paper addresses this dilemma. Through an analysis of the capabilities required by the air mobility customer in the year 2025, the required attributes of the air mobility system are identified. A system and concept of operations are then proposed that will best meet customer needs while employing systems and technologies currently in development and those that will be available by the year 2025. Our thesis is that the air mobility concepts proposed in this paper, in conjunction with the employment and integration of innovative technologies and systems, will allow the United States to adequately meet future national objectives.

Note

1. Lt Col Robert L. Bivins et al., "***2025*** Alternate Futures," unpublished white paper, Air University, n.d. This paper outlines possible future scenarios for the ***2025*** project.

Chapter 2

Required Capabilities

The United States requires an air mobility capability to deploy robust and flexible military forces that can accomplish a variety of tasks. These tasks include deterring and defeating aggression, providing a credible overseas presence, countering weapons of mass destruction, contributing to peace operations (multilateral and unilateral), and supporting counterterrorism efforts. This capability will still be necessary in 2025, but the air mobility system must be carefully developed and nurtured.

In the past, the US military failed to maintain the airlift capability required to meet identified requirements.[1] Even today, concerns remain as to whether our airlift capability can meet the increasing number of requirements. "Military officials admit that even if they can buy as many C-17s as the Air Force wants, there will still be a need for more airlift as the US withdraws from bases overseas."[2] The pending retirement of the C-5, C-141, and much of the C-130 fleets, the aging of remaining air mobility assets, and the requirement to replace the aforementioned in what are likely to be austere economic conditions, are among the challenges facing the air mobility system. To meet these challenges, an analysis of the customers, their needs, and the attributes required of the air mobility system of 2025 is necessary and serves as the foundation upon which any future airlift system should be built.

Customer

The military airlift system supports attaining national objectives continuously through all levels of conflict. "The primary responsibility [sic] of America's military is to deter potential adversaries or fight and win wars decisively."[3] To meet these responsibilities, the airlift system supports the following: US military and civilian agencies, allies, friendly and other foreign governments, multinational organizations, nongovernmental organizations, private volunteer organizations, and other entities deemed necessary to support national objectives. Due to the unique air mobility capabilities of the United States, it is often the only option for meeting these customers' air mobility needs.[4]

In meeting the needs of the customer, the airlift system must address two primary problems. The first is the horizontal problem of getting personnel and materiel from their locations to the theater of operations in a timely fashion. The second is the vertical problem of transferring personnel and materiel between the airlift platform and surface mediums (fig. 2-1). It will be imperative for war fighters to access an efficient system to have materiel delivered directly to the battle area in a time-sensitive manner.

The airlift system is composed of internal systems including airlift platforms, infrastructure, and payload operations control. These systems must merge with both commercial and military land, sea, and space lift systems to provide continuous mobility support. In providing this support, airlift operations will employ a variety of platforms. To best serve the airlift customer, it is imperative that these platforms be part of a seamless mobility system capable of operating throughout the spectrum of conflict.

History has frequently shown the need for deploying forces in a timely fashion over great distances and in sufficient numbers to achieve a credible numerical advantage. Currently, personnel and materiel are not only deployed to theater staging bases but are also transshipped to the employment

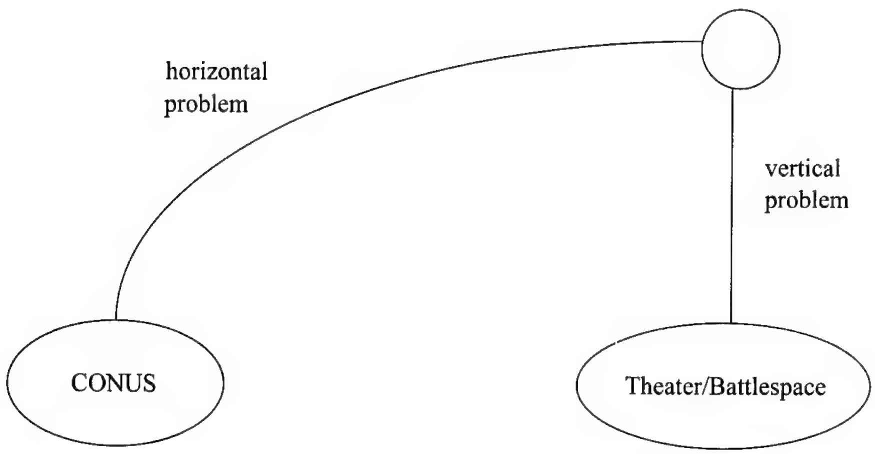


Figure 2-1. Horizontal and Vertical Problem

location. In the past, the US has been able to create a "safe" theater transshipment infrastructure. However, it is a slow, labor-intensive process to move personnel and materiel from the strategic to tactical cargo movement mediums for delivery to final destination. Even today, we cannot meet the battle space demands of immediate and direct delivery of personnel and materiel.[5]

By 2025, due to the proliferation of weapons of mass destruction as well as the high potential for a worldwide revolution in military affairs, there will be a drastic increase in the speed, efficiency, and lethality of battle.[6] Concomitant with these increases is the need for rapid support to the war fighter. Modern conflict has complicated this problem by creating a rear battle area that is much more vulnerable, thereby denying the assurance of a safe transshipment infrastructure. According to Dr Eliot A. Cohen, rear area security may no longer be possible in as few as 20 years due to the "precision revolution," the emergence of alternative forms of airpower (such as UAVs, cruise missiles, etc.), and the changing nature of platforms resulting from the increased use of stealth, range, and information power.[7] These wartime challenges are compounded by the need to respond to natural and man-made disasters, nation assistance, and additional operations other than war. Meeting our nation's complex air mobility needs in time of both conflict and peace requires a flexible and responsive system designed to enhance the abilities of the user.

Recognizing the evolving battlefield requirements and mobility constraints, the US Army is adapting to improve its capabilities while reducing the impact of mobility constraints. "Force XXI will be a more resource-efficient Army, with capabilities enhanced through information age technologies. It will allow us to project power into any area of the world more quickly, more effectively, and with greater efficiency as part of a joint effort."[8] However, Army modernization cannot overcome many inevitable constraints. "The Army of 2010 will be based primarily in the continental United States. While we will continue to maintain a minimal forward presence in some parts of the world, we will depend on a combination of airlift and sealift to execute the Nation's strategy."[9] If the war fighter is to succeed, the airlift system must address the customers' needs and not expect the customers to sacrifice their capabilities for the sake of eliminating air mobility constraints.

Required Attributes

The air mobility system of 2025 will provide three basic functions: personnel delivery, cargo delivery, and aeromedical evacuation (AE). To accomplish its mission, the following air mobility system capabilities are proposed (table 1).

Table 1
Measures of Capability

Capability	Measures
Point of Use Delivery	Within 10 meters of designated target
Long Range	12,500 miles unrefueled[a]
Total Resource Visibility	Near-real-time information
Interoperability	Standardized containers
Survivability	Standoff range of 150 miles[b]
	Threat detection/defeat within 150 miles
Infrastructure	Less is better

[a]Based on no in-theater basing and multiple delivery points.
[b]150 miles provides over-the-horizon protection up to 20,000 feet.

Point of Use Delivery and Extraction

"The giant airbases of today will become the bomber cemeteries of a future war."[10] Although the world envisioned in 1958 by General P. F. Zhigarev has altered dramatically, the projected lack of established bases for transshipment and the vulnerability of forward bases to diverse threats will require the capability for airlift systems that can provide direct delivery from CONUS to the point of intended use, and direct extraction from those operational sites without the availability of an established support infrastructure.

"Precision airdrop is a critical Air Force capability."[11] Personnel and equipment must be delivered with essentially pinpoint accuracy. Aircraft security can be greatly enhanced if the airlifter can perform its delivery mission while remaining at "standoff" range from the hostile battle space. To best serve the war fighter, delivery accuracy of 10 meters from the intended target is required. The delivery system can be either powered or unpowered, such as a parasail or rigid-winged glider/container (a smart box that directs itself to a specific destination). Current systems continue to be highly inaccurate, are susceptible to wind and altitude variances, and require the cargo aircraft to fly through or above the threat airspace, increasing the aircraft's vulnerability to hostile fire. Although grossly exaggerated, a Pentagon source highlighted the need for increased precision by stating that when "Dropped from altitudes of 10,000 ft, to stay above anti-aircraft fire, the parachuted supplies would be lucky to hit Yugoslavia."[12] In fact, accuracies achieved during Operation Provide Promise were significantly better than this estimate and showed improvement throughout the operation. These improvements, however, were more in line with the 350 yards from target (when dropped from 1,100 feet) required by Air Force air-drop standards.[13] These standards will not be sufficient for operations in 2025.

Like delivery, extraction of cargo and personnel could occur in hostile and austere environments with no runways available. Proposed extraction systems will allow the airlift platform to recover personnel and materiel without landing. Because most operations dictate retrograde at a lower rate than the actual deployment, not every mobility platform would be required to accomplish direct extraction.

Long Unrefueled Range

Due to projected CONUS force basing in 2025, the United States may lack established airfields in-theater for transshipment points.

To project power globally, strategic lift platforms will need an unrefueled round-trip range of at least 12,000 miles.[14] This will allow deployment from CONUS bases directly to the theater of operations and return without refueling. Air refueling will still be a requirement to increase the flexibility of the air mobility system and allow changes to occur en route.

Total Resource Visibility

Total resource visibility (TRV) will provide visibility of all resources from acquisition through employment to all command and control elements. Additionally, it will allow cognizant authorities to redirect in-transit cargo and troops as needs dictate. Although several improvements are underway, current in-transit visibility (ITV) systems can identify in-transit payloads only by specific aircraft and mission number, and are limited in their ability to adapt to rapidly changing situations.[15] During Operation Desert Shield, the time-phased force and deployment data (TPFDD) could not identify the impact of altering the sequence of deployment on military operations and led to detrimental decisions without comprehensive analysis.[16] The TPFDD and other Joint Operation Planning and Execution System databases are projected to be incorporated into systems such as the Global Command and Control System (GCCS) which will merge it with other databases.[17] Although the GCCS as currently designed will greatly enhance existing capabilities, it will be insufficient for future TRV needs.

Survivability

Air mobility planners have not adequately considered the first principle of logistics of the former Soviet Union, "The organization of the rear must reflect the character of the war and the nature of the fighting."[18] Along with this concept, current air doctrine states that "Logistics capabilities must be designed to survive and operate under attack; that is, they must be designed for combat effectiveness, not peacetime efficiency."[19] Through the year 2020, the notional strategic cargo airlift capability calculations to support national objectives rely exclusively on large, conventional airlift platforms. These platforms incur substantial constraints resulting from weapon system vulnerability, infrastructure requirements, materials handling equipment (MHE) needs, and other limitations. In addition, the projections do not account for unanticipated platform attrition, airframe gentrification, or significant forward basing restrictions.

Increased reliance on the civil reserve air fleet (CRAF) for mobilization and expanded commercial transport support could result in the costs of CRAF mobilization exceeding those that are acceptable and in preventing the projection of US military power.[20] In addition, over-reliance on CRAF could hinder effective response by military forces, resulting in interests vital to the United States being compromised. Although this may be a very stressful scenario, it must be considered.

In an effort to address the above limitations, the airlift system must be able to project forces into the forward battle space. "Our vital interests—those interests for which the United States is willing to fight—are at the endpoint of 'highways of the seas' or lines of strategic approach that stretch from the United States to the farthest point on the globe."[21] Lacking secure rear areas of operation, the airlift platforms must be survivable under potentially hostile circumstances.

Depending on the sophistication of the threat, the hostile environment could extend a considerable distance from the actual battle space.[22] The size and importance of airlift platforms present a very lucrative target to both ground and air threats. To be effective, they must be able to detect and counter these threats either by direct active measures or by avoidance. Also, support systems and equipment must be able to survive in hostile environments to include those contaminated by nuclear, biological, and chemical agents.

To help counter the above threats, airlift platforms, direct delivery systems, and unmanned combat aerial vehicles (UCAV) must incorporate technologies such as "low observables," multispectral sensors, and directed energy weapons.[23] According to the Advanced Research Projects Agency (ARPA), advances in coatings, materials, and design will lead manufacturers away from radical designs like the F-117 and B-2 shapes. The future will see smaller, more subtle changes and aircraft designers will be able to treat less different airframes and get equivalent performance (to today's stealth shapes). It will be a healthy competition between materials and coatings, at least among US competitors.[24]

Intermodality

Intermodality is a basic requirement for airlift systems. Cargo must be configured for direct transfer between air, land, sea, and space lift systems and operational use at delivery destination. Because we anticipate the requirement to transport military cargo on commercial carriers of all mediums when possible, military payload configuration must comply with national and international standards. Through cooperative international development, these configurations also allow direct synergistic support among operational allied, coalition, and US forces.

Modularity

The platform payload interface will allow selected payloads to provide diverse mission capabilities to the airlift platform. The airlift platform will be capable of passenger, cargo, and aeromedical evacuation configurations. Additional payloads, such as power generation, information support, or maintenance systems will primarily enhance the airlift platform. Other payloads may include special mission configurations, such as reconnaissance, or auxiliary capabilities such as offensive and defensive weapon systems. Also, many special purpose operations such as psychological operations, aerial spraying, fire fighting, and developmental test and evaluation can be supported through modular configuration of airlift platforms. Since the airlift platform will be supporting these types of users, it must be equipped with very robust power, oxygen, and communication systems in the event of simultaneous taskings.

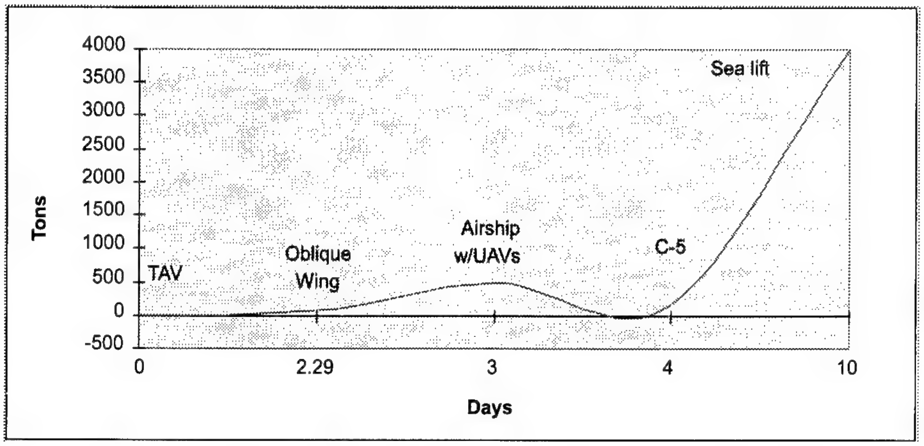
Interoperability

Interoperability is the capacity to seamlessly interact with all airlift system customers and operational partners. The US mobility system will operate with commercial systems globally and conduct multinational operations. The airlift system components will be designed to maximize compatibility with airlift system components and payload configurations of other government and private organizations. The development of universal standards and compatible equipment by international transportation organizations should eliminate most interoperability problems due to equipment and payload.

Responsiveness

> At the outset of war, time is the supreme factor. Do not let us forget that the aggressor is also concerned with the time factor; he is ready, otherwise he would not have provoked armed conflict; he inevitably hopes and plans for a quick decision, since no one would wish for a long war if it could be avoided; moreover he wants a decision before his opponent has had time to turn his capacity into the new activities which war calls for.
>
> —Lord Tedder

Responsiveness alludes to timeliness. It is the ability to deliver personnel and materiel exactly when and where the user requires them. Although speed from point A to point B is important, it is of little use if arrival time at the battlefield is delayed by repackaging or transshipment. In light of this, airlift needs a faster shipment "system" as much or more than faster aircraft (fig. 2-2). Other enhancements such as the ability to change the place of delivery while the personnel or materiel are en route will also improve responsiveness.



Notes: Responsiveness - time for cargo to move from point of origin to point of use in days.
Except for airships with UAVs, all cargo must be moved from point of origin to airfield (approximately 24 hours).
C-5s and airships with UAVs deliver to point of use; cargo moved via other systems must be transshipped in theater (approximately 24 hours).
Times do not include airlift platform preparation times.
In-flight times based on 6,000 miles one way.

Figure 2-2. Responsiveness

Cost

To be effective in 2025, the airlift system must meet airlift requirements throughout the airlift operational spectrum. These missions have vastly different operational requirements such as responsiveness, volume, and defensive capabilities. Given a finite supply of labor, energy, and materiel, the United States should field an airlift system that considers cost factors in determining the mix of airlift platforms and support systems. Also, cost factors should be considered when determining policy, particularly when vital interests are not at stake.[25] These costs, while primarily monetary, also involve the expense of political capital as it relates to the mobilization of reserve and CRAF assets. Therefore, the airlift system will be composed of both technologically evolutionary and revolutionary systems that optimize capability and costs within the constraints of the time frame considered.

Other Considerations

Airlift platforms will most likely be required to employ systems that comply with international environmental restrictions and eliminate existing negative effects. Propulsion systems should reduce to acceptable limits or eliminate negative environmental effects from hypersonic systems. The capability will exist to engineer systems to eliminate noise pollution. These include managing boundary effects to eliminate sonic booms. Materials technology will be able to produce structures composed of compositions that eliminate the requirement for scarce resources. Airlift direct transfer and short takeoff and landing/vertical takeoff and landing (STOL/VTOL) systems can eliminate requirements for extensive concentrated terminal facilities and materials handling and storage infrastructure, thus reducing resources demand, urban development congestion, and air traffic congestion.

The need for airlift support can also be reduced significantly through other efforts. System designs should incorporate the capability to perform multiple functions and use electronic transfer to allow these systems to repair and update capabilities. These options will eliminate extensive logistics support and airlift requirements. In

addition, active search methods will identify alternate sources of materiel in the theater of operations, determine acquisition options, determine support operations, and eliminate many airlift requirements. At the operations-other-than-war end of the airlift spectrum, air mobility's ability to "show the flag" will continue to demonstrate government-to-government and military-to-military relations. These can be much more visible to a population and usually much less threatening to a populace than the naval presence of a carrier battle group.[26]

The required capabilities of the air mobility system in 2025 have been identified as follows: point of use delivery and extraction, long unrefueled range, total resource visibility, survivability, intermodality, modularity, interoperability, responsiveness, and cost. Each serves an integral purpose in a synergistic whole. If the air mobility tasks required to meet national objectives in 2025 are to be accomplished, each of these capabilities must be present in the air mobility system.

Notes

1. Lt Col Duane C. Johnson, "Strategic Airlift and Sealift: Both Have Long Suffered from a Capabilities Versus Requirements Disconnect. What Is the Prognosis?" (Maxwell AFB, Ala.: Air War College, 1990), 8–9.

2. "Close the U.S. Strategic Airlift Gap," *Aviation Week & Space Technology* 141, no. 17 (24 October 1994): 66.

3. Sheila E. Widnall, secretary of the Air Force and Gen Ronald R. Fogleman, *Global Presence, 1995* (Washington, D.C.: Department of the Air Force, 1995): 3.

4. Lt Col Marcel Duval, Canadian Armed Forces, "How to Improve the Response Time and Reduce the Costs of UN Operations through a Better Use of the World's Air Assets" (Maxwell AFB, Ala.: Air War College, April 1995), 12.

5. Lt Gen William G. Pagonis, *Moving Mountains: Lessons in Leadership and Logistics from the Gulf War* (Boston: Harvard Business School Press, 1992). This book outlines the six-month logistics build-up phase required to prepare personnel and materiel for Operation Desert Storm.

6. Togo D. West, Jr., secretary of the Army and Gen Gordon R. Sullivan, *Force XXI: America's Army of the 21st Century* (Fort Monroe, Va.: Office of the Chief of Staff, Army, 15 January 1995): 8–18.

7. Dr Eliot A. Cohen, "Long Range Air Power and US Military Strategy," address to congressional staffers, Washington, D.C., 7 March 1996.

8. West, 9.

9. Ibid., 31.

10. Charles M. Westenhoff, *Military Air Power, The CADRE Digest of Air Power Opinions and Thoughts* (Maxwell AFB, Ala.: Air University Press, 1990), 126.

11. Sheila E. Widnall, secretary of the Air Force and Gen Ronald R. Fogleman, *Air Force Executive Guidance, December 1995 Update* (Washington, D.C.: Department of the Air Force, 1995): 15.

12. Frederick Painton, "High-Altitude Help," *Time* 141, no. 10 (8 March 1993): 37.

13. MCI 10-202, *Aircrew Training Programs: Policies, Organization, and Administration*, vol. 1, 15 October 1995, 49.

14. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 10.

15. John L. Cirafici, *Airhead Operations—Where AMC Delivers: The Linchpin of Rapid Force Projection* (Maxwell AFB, Ala.: Air University Press, 1995), 80–81.

16. Pagonis, 89–93.

17. *User's Guide for JOPES (Joint Operation Planning and Execution System)*, 1 May 1995, 14–19.

18. Maj Gen Julian Thompson, *The Lifeblood of War: Logistics in Armed Conflict* (London: Brassey's, 1991), 302.

19. Air Force Manual 1-1, *Basic Aerospace Doctrine of the United States Air Force*, vol. 1, March 1992, 15.

20. Not only would it cost the US a great deal to provide incentives to CRAF carriers, but modifications to civil aircraft are not cost-effective in all cases. Some CRAF carriers have elected to not renew their CRAF contract agreements after Operations Desert Shield/Desert Storm due to the loss of routes, traffic, and market share. It may not be possible for the US government to pay the costs of an effective CRAF in 2025.

21. John H. Dalton, secretary of the Navy, Adm J. M. Boorda, and Gen Carl E. Mundy, Jr., *Forward... From the Sea* (Washington, D.C.: Department of the Navy, 1994), 2.

22. Cohen.

23. *New World Vistas*, summary volume, 9, 12.

24. David A. Fulghum, "International Market Eyes Endurance UAVs," *Aviation Week & Space Technology* 143, no. 2 (10 July 1995): 40.

25. Lt Col Ronald L. Bean, "Air Mobility—Pivotal Non-Lethal Capability: Where are we going with Peacekeeping?" (Maxwell AFB, Ala.: Air War College, April 1995): 1.

26. Currently, airlift aircraft show the flag worldwide on a daily basis.

Chapter 3

System Description

Certain craft were evaluated in light of required capabilities to determine their place in the Air Mobility system of 2025.

Platform Options

They include transatmospheric, hypersonic, and supersonic vehicles, airships, in-ground-effect wings, very large aircraft, and unpowered and powered delivery systems using both manned and unmanned technologies. In addition to platform options, additional equipment such as standardized cargo containers and onboard materiel-handling equipment required to operate these platforms are described below, and the technologies required are indicated. The required capabilities identified in chapter 2 will determine the best mix of options.

Transatmospheric and Hypersonic Vehicles

There have been two noteworthy attempts to develop a transatmospheric vehicle (TAV) to provide an airlift platform that meets the rapid in-transit response criteria for high-priority payloads.[1] The advantages of TAV systems include decreased vulnerability due to the lack of en route infrastructure and support facilities. It is intended that the TAV incorporate the environmental support systems to meet crew, system, and payload needs while employed in exoatmospheric operations, including the capabilities for crew transshipment infrastructure or platform replenishment support. The TAV allows transport of cargo to any location globally within one hour from departure.

Unfortunately, the projected TAV technological requirements and operating parameters make this aircraft infeasible for most military payload requirements. Although TAV sorties could reach any location on earth in one hour, payload size would be limited to 10,000- to 30,000-pound capacity. In addition, typical TAV requirements include conventional runways of at least 11,500 feet and extensive specialized support infrastructure as well as an extensive turnaround time to prepare the vehicle for another mission (anticipated to be approximately five days).[2] TAVs should have the capability however, to deliver limited payloads quickly once the vehicle is prepared and the cargo loaded. While certainly suited for small, notional six-man team delivery, this vehicle is unlikely to be used for movement of moderate to large payloads.

Supersonic Transport

Force projection depends on delivering personnel and/or materiel where they are needed in the shortest time possible. The best military strategies and tactics are of little value if the right soldiers, weapons, and supplies cannot be in the right place at the right time. Consequently, the movement of personnel and equipment at supersonic speeds is alluring. Two possible options for supersonic airframes are the "standard" Concorde SST (supersonic transport) design and the unique oblique flying wing design.

While Europe's Concorde has logged more than 100,000 supersonic flight hours (more than all the military services combined) in its 20 years of commercial service, its 100-passenger capacity is much too small for military transport use.[3] However, in addition to the US, both Europe and Japan are spending significant time and money researching supersonic transport vehicles that will carry up to 300 passengers, a size that could have military applications. In addition, market research for supersonic travel has shown that if the price of a ticket

could be brought to within 10 to 20 percent of current subsonic fares, there would be a substantial market. "Studies show a potential high speed aircraft market of 315,000 passengers per day by the year 2000, and 600,000 per day by 2020. To meet this demand, 500–1,000 high speed civil transports would be needed."[4] This current civil attention is advantageous since the cost of research and development for aircraft design is prohibitive for the Air Force. At an "estimated cost of $15–20 billion to bring a new supersonic transport to market," it is imperative that the Air Force depend on the civil sector for overall design.[5]

Unfortunately, even civil sector attention is no guarantee. Large leaps in technology are required to build an environmentally safe supersonic airlifter at a price the struggling airlines could afford. Although some scientists are confident that environmental barriers can be overcome and noise reduction ideas for takeoff and landing will work, there is much work to do in the development of advanced materials. "Needed are ceramic matrix composites that can withstand the prolonged high temperatures in the new engine combustors, and lightweight, durable composites and super alloys for the airframe and engine components to hold down the airframe's weight and fuel consumption."[6] Even the application of military sensor technology replacing windows with computer displays to reduce weight is still in its infancy. Though new designs will have longer ranges than the Concorde, they still come far short of the desired 12,000-mile unrefueled range. "Current SST designs have a range of 5,500–6,000 nautical miles and require 4,000 meter (13,000 feet) long runways."[7] This obviously places a restriction upon how far it could go and where a military SST would be able to operate. The need for a truly long-unrefueled-range aircraft is unlikely to be met by a supersonic transport by the year 2025.

Oblique wings may provide more efficient supersonic flight. "Preliminary studies indicate in direct comparison with the Boeing 747, that the oblique wing may be 16–30% cheaper to fly."[8] Like the "standard" Concorde design, for an oblique wing to be practical there must be a need to carry a large number of passengers. "A passenger or cargo carrying wing would have to be about 7 feet thick to allow people to stand, and this in turn dictates a 50 foot chord and 500 foot wing span. Such an aircraft would be able to carry more than 500 passengers."[9] The vehicle would fly about a 60-degree angle at top speed of between Mach 1.6 and 2.0 but rotate to about 30 degrees for takeoff and landing. While the oblique wing concept is slightly slower than other designs, its advantage is that it is very efficient. "Initial wind tunnel tests indicate that the oblique wing would have a very good lift to drag ratio (as high as 30:1), and subsequently low thrust requirements even for takeoff and acceleration."[10] The low power requirement advantage is obvious when considering the continually stiffening noise restrictions surrounding US airports.

There are two impediments to the development and use of an oblique wing design. First, though feasible, the technology to produce and fly such a design may not develop because of a lack of interest at the civilian level. Even though a flying scale model has been developed, research shows little interest in pursuing further development has been demonstrated by civil aviation manufacturers.[11] Unless the public sector decides such a unique design is safe and passenger friendly, there is little hope such a craft will be developed regardless of its advantages.

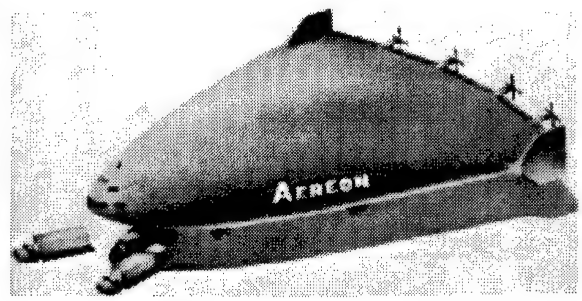
Secondly, significant support problems hinder the development. Not the least of these is the extensive and costly renovation of existing infrastructure to accommodate an aircraft nearly twice as large as any currently in existence. Individually, these impediments might be overcome. Together, they represent a commitment of resources inconceivable, given the projected availability of future funding. For these reasons, we believe the costs outweigh the benefits of such vehicles.

Airships

Since the Hindenburg catastrophe in 1937, airship development has taken a backseat to aircraft development. Because of this, opportunities exist for tremendous advancements in design and capability with the application of technologies that are common in the aircraft industry. The application of probable 2025 technologies to airship design could yield tremendous increases in overall capabilities with substantially decreased delivery times at a fraction of current per-mile costs for air cargo movement.

Current airship development efforts have concentrated on the application of materials technologies to the airship structure. These efforts include the introduction of composite framing and high strength-to-weight fabrics. Additionally, developments in engine technology have increased speed and controllability while decreasing the manpower-intensive nature of previous airship operations (fig 3-1). These developments have reinvigorated inquiry into the future role of airships. They have not, however, expanded the capabilities of the airship beyond those achieved before World War II.[12]

Air mobility requirements in 2025 will demand a substantial increase from existing airship capabilities. These include a 500-ton useful lift capability, maximum airspeed of 250 knots, maximum range at maximum gross weight of 12,500 miles, and a defensive/stealth capability. Although substantially slower, the airlift capacity of this notional airship would be nearly six times that of our largest airlift platform, the C-5B.[13] Even with the difference in delivery time (approximately a 2-to-1 advantage over the C-5) the airship would still have three times the effective ability of the C-5B (fig. 2-2). Cost of airship production is also low since cost per unit produced could be approximately one-third that of the C-5B.[14] In addition, with the integration of UAVs and airships, the capability exists to deliver personnel and equipment directly to the user (point of use delivery), thereby, eliminating transshipment time and reducing infrastructure requirements and costs.



Source: William J. White, *Airships for the Future* (New York: Sterling Publishing Co., 1978), 127.

Figure 3-1. Large Cargo Airship

Technologies that will have a great impact on the development of Airship 2025 include future composite materials, advanced computer modeling capabilities from which structural analysis and inexpensive test "flights" can be conducted, and nano-technology innovations that will decrease the weight and size of onboard systems. Additional developments in stealth/low observables technologies will make what is already a low-signature target (due to its composite structure) more survivable. The development of stand-off delivery vehicles (UAVs) will also increase the airship's survivability by allowing the airship to loiter well outside the battle space threat area while the UAVs provide point of use delivery to forward deployed units.

The possible commercial applications of airships are numerous. Commercial air carriers are currently pursuing larger capacity aircraft to increase the efficiency of air transport. The substantially cheaper per-unit cost of airships, combined with their superior capacity, hold great promise for long-range passenger and package delivery. Additionally, civilian adoption of airship operations similar to those proposed in this paper could usher in a new era of innovation in the commercial air freight

industry where direct delivery of goods is the baseline product.

In-Ground Effect Wings

Wing-in-ground effect vehicles (or wingships) are another type of platform design that could provide the size, weight, and volume of lift required in 2025 (fig. 3-2). Wingships are hybrid sea/air vehicles capable of very heavy lift over extremely long ranges. They do so by taking advantage of the ground effect phenomena to provide a significant increase in lift capability over what conventional aircraft are currently capable. Because of these phenomena, it is technologically feasible to build vehicles that are at least three times larger and 10 times heavier than the largest airplane currently built.[15] Developed initially by the Russians in the 1960s, the first wingship (named the "Caspian Sea Monster") was capable of lifting 540 tons and cruised at 310 miles per hour.[16] This vehicle took off and landed on the sea and held a steady altitude of 10 feet above the surface. Current wingships have the capability of flying between 20 and 90 feet above the surface of the sea and can cruise at 400 knots. Higher altitudes are possible when necessary to transit small land masses or avoid shipping or other obstacles, but these altitudes cause a significant decrease in fuel efficiency. Because of their shallow draft, these vehicles are able to load and unload in shallow and/or undeveloped ports where deep-draft vessels are unable to go.

Developments in lightweight structures and materials have made it technologically feasible to construct a wingship capable of lifting 5,000 tons, although the engines required to power it are still a long way off. The Advanced Research Projects Agency (ARPA) of the Department of Defense (DOD) recently analyzed a wingship that was able to transport 1,500 tons over an unrefueled range of 10,000 nautical miles at a cruising speed of 400 knots.[17] Even with this kind of lift and the potential ability to attain altitudes of almost 10,000 feet, the most significant challenge is designing engines that can produce the enormous power to break free of the water and maintain the required power levels for an extended period of time at low altitudes where temperatures are relatively higher than those experienced by conventional aircraft. Other technological problems include stability problems as well as the difficulty of flying over turbulent seas.[18] These problems could potentially be solved by using enhanced computer processing to assist in wingship control.

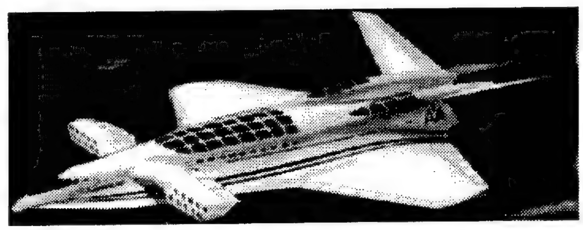


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Figure 3-2. Conceptual Wingship

In addition to these technological drawbacks, the wingship cannot provide the direct delivery and extraction required in 2025 since they are confined to waterways only and are susceptible to interdiction in narrow passageways such as the Suez and Panama Canals. They also require an infrastructure outside of the continental United States, even though that infrastructure does not have to be extensive or large. While the wingship could conceivably deploy and recover UAVs, the UAVs would all have to be powered, driving up the cost of the air mobility system. Ultimately, the wingship is unable to provide a seamless point of use delivery capability to the war fighter without another form of transportation (rail, truck, etc.) to get the cargo and equipment to the battlefield. Because of this, we believe it is not a good platform for the air mobility system of 2025.

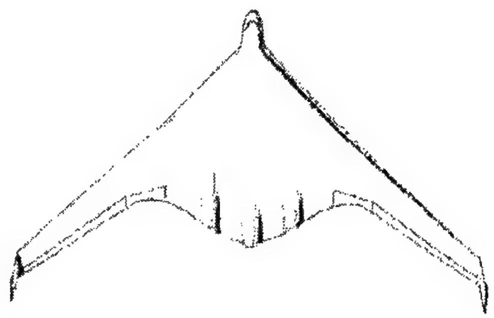

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Figure 3-3. Very Large Aircraft

Very Large Aircraft

Commercial aircraft manufacturers, in concert with governmental agencies, are currently showing a great deal of interest in the development of very large aircraft (VLA) (fig. 3-3). Shelby J. Morris, head of a NASA/Langley engineering group brainstorming the concept, states that "largeness is a virtue up to a point, but we're not sure of how large is large enough and how large is too large."[19] These developments are reliant on the extensive existing infrastructure of the United States and other developed first world countries and are pertinent to operations in these areas.

Current VLA concepts include expanded conventional transports, blended wing bodies, and a variety of other designs. These concepts propose maximum payloads ranging from 300,000 to 1,000,000 pounds with wingspans as large as 330 feet.[20] Such designs are problematic, as their sheer size vastly increases the infrastructure required to support them. Possible solutions to this problem include the creation of landing piers along lakeshores.[21] Cost and environmental problems associated with this idea greatly undermine its feasibility and serve to highlight similar problems associated with the renovation of existing structures.

These infrastructure problems are even more daunting when one considers the lack of infrastructure available to military forces deployed abroad. Future VLAs are likely to face the same problem inherent with our current very large aircraft, the venerable C-5B. This problem is the requirement for an extensive supporting infrastructure unavailable in a high-threat, forward deployed military operation.

The VLA exhibits a high profile during operations. Even if the adversary lacks sufficient capabilities to directly contest air superiority with the United States, the VLA's conventional operating procedures induce reliance on a fixed infrastructure. This infrastructure represents an extremely vulnerable center of gravity, as it can be targeted by a variety of standoff air-to-surface and surface-to-surface weapon systems to ensure air base denial.[22] In addition, man-portable antiair weapon systems enhance the capability to infiltrate and target US theater insertion capability. The VLA's most significant advantage is its increased lift capability. However, the operational and infrastructure requirements to service this increased capacity present two key vulnerabilities: the need to fly into the battle space thus presenting a high-value target and the need to offload/transship its cargo at a suitable in-theater airfield, itself a center of gravity in the highly lethal and fluid environment of 2025.

In the final analysis, the main problem with VLAs is that they remain an evolutionary change in airlift capability and have failed to adequately evolve to meet mission requirements to survive and support operational needs in a threat environment. In other words, VLAs are doing the same old thing, the same old way, with new/larger equipment. The VLA has utility in supporting nonthreat operations such as humanitarian assistance, but it is a system that complements airlift operations, without providing the necessary capabilities to support potentially hostile operations in 2025.

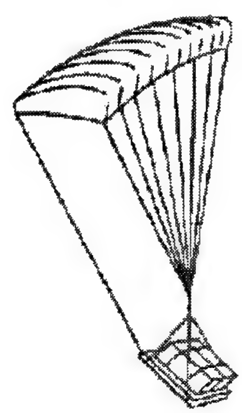
Delivery Vehicles

Since the air mobility system of the future may not have operationally supportable access to airfields (large or small) or trans-shipment infrastructure outside of the continental United States due to political, environmental, threat, and/or infrastructure considerations, there must be a method to deliver personnel and equipment directly from the large airlifter to the precise location requested by the war-fighting commander. The current airdrop capability of the US Air Force raises some tricky problems, most notably hitting small targets from high altitudes (above 10,000 feet), the requirement for large drop zones, and the necessity of having personnel on the ground to monitor weather conditions during the actual drop. As mentioned previously, during the recent humanitarian airdrop into Bosnia, there was significant concern over the ability to find and hit small, obscure drop zones while at night and/or in poor weather.[23] The war fighters of the future will need to place equipment and personnel within 10 meters of the intended target during all weather conditions and in any type of terrain as well as during potentially hostile situations. This precision capability will be required not only during the initial insertion of forces but also during the following resupply and sustainment efforts. Several unpowered vehicles currently in development show promise in this respect.

Unpowered Delivery Systems

One of the most promising unpowered delivery vehicles is an autonomous system that can deliver heavy payloads to within about 30 feet of the intended target. This system, called the Guided Parafoil Aerial Delivery System (GPADS), uses a parafoil that is 49 feet long, 8 feet deep, spans 150 feet, and weighs 1,600 pounds (fig. 3-4). The guidance package utilizes a global positioning system (GPS) receiver, compass, pressure altimeter, air speed indicator, and a computer to sense and correct in real time for changes in wind speed and direction and compensates for movement of the payload and canopy. Designed to guide a total load of 42,000 pounds from an altitude of 25,000 feet and 12 miles away from a target, an airborne division would require a mix of 450 heavyweight and medium-weight parafoils in addition to 450 parafoils that could deliver 1,200 pound loads.[24] Even if the war fighter of 2025 requires less overall weight to deploy, parafoils of the future would need to carry significantly heavier loads and be capable of delivering them from farther away.

Another system that is complementary to the GPADS is being developed by NASA as a method for returning cargo and crews from space in an autonomous mode. Termed the *Spacewedge*, it allows cargo to be deployed from an aircraft up to 20 miles away from the intended landing zone and potentially brought within 100 feet of the target. To fly at about 20 miles per hour with a sink rate of 10 feet per second, this system uses a parachute and a guidance package composed of a GPS receiver and antenna, an uplink receiver, an altimeter, and electronic compass as well as a 80196-based flight control computer. It is not as accurate as the GPADS. The objective of this program is to be able to deliver a full-scale



Source: Robert W. Rodier et al., *Master Plan for Airdrop Future Systems,* Natick TR-91/037L (Natick, Mass.: US Army Research, Development & Engineering Center, June 1991), 35.

Figure 3-4. Parafoil Delivery System

space vehicle to a soft landing at a sink rate of about 2.5 feet per second.[25]

A parafoil system that combined the best characteristics of these two systems would provide precise delivery of personnel and equipment to the war fighter. The ability to drop heavyweight loads would allow the war fighter to insert most, if not all, of his heavy equipment within 10 meters of the intended target. This ability would allow the advantage of surprise and also would be very difficult to defend against since the choice of landing site increases significantly. The ability to drop the load from approximately 150 miles away also enhances surprise (not to mention aircraft survivability) by not announcing the location of the drop zone. In addition, several loads could be dropped simultaneously in opposite directions, allowing the greatest amount of coverage if required by the situation. Finally, personnel could be dropped in containers, reducing the parachute training required for individuals and allowing more concentration of troops in a particular area. If the psychological aspects of lack of control warrant adjustments, a man-in-the-loop option for control of the container can be developed for dealing with emergency contingencies.

A disadvantage of this parafoil delivery system is that it relies on a GPS link that could be either disrupted by the enemy or used by the enemy to locate the delivery system and either shoot it down or otherwise compromise the attack. Use of an internal guidance package (such as a micro-internal navigation system device) that did not need external links to determine its location would take care of this problem. The package would still need to receive data about wind direction and speed but as long as it did not send out signals it could retain its stealthy characteristics. Another disadvantage of a parafoil system (or any unpowered system) is that the large parafoils and containers could potentially become excess material on the battlefield. While soldiers traditionally use most available materials in combat, any excess material could be difficult to dispose of, becoming an environmental issue once the war or conflict was terminated. In a special-operations-type scenario, this debris could indicate the presence of troops that were attempting to operate in a covert mode. Advances in materials technology might be able to produce materials that rapidly degrade or reconfigure for alternative uses. Finally, the main disadvantage to an unpowered parafoil system is that while it can deliver cargo and personnel very accurately from high altitudes and significant distances, it cannot extract the troops once the mission is complete (or during a fighting withdrawal). Also, these systems are vulnerable to severe local weather conditions that may degrade performance significantly.

Powered Delivery Systems

Powered unmanned aerial vehicles show enormous potential for direct delivery and extraction of cargo and personnel to and from the customers' desired location. The use of UAVs in this role would minimize the risk to humans by removing the transport pilot from the battlefield and would also maximize the payload of the UAV by not having to lift additional crew members. UAVs showed recent success in Operation Desert Storm and are currently being used in the operations in Bosnia, although in exclusively reconnaissance-type missions. Currently these aircraft are small and are able to carry only small sensor/communications payloads. Future technological advances (such as more powerful propulsion units, more versatile airframe designs, lightweight but strong materials, etc.) may allow the development of a UAV that will be able to lift and maneuver a standard cargo container carrying personnel and/or equipment. To accomplish these tasks, a UAV must have the capability for full or near full autonomous flight to make round trips from the airlifter to an unimproved

location and back while surviving in a potentially hostile environment.

The requirement to deliver cargo and personnel wherever the user needs it demands that a UAV be capable of taking off and landing vertically or at the very least in a very short distance, allowing the combatant commander maximum flexibility in placing troops and equipment. Four powered vehicle designs could potentially fill this requirement: a helicopter-type vehicle, an x-wing design, a "jump jet," and an ornithographic vehicle. A helicopter-type vehicle already exists that is capable of fully autonomous vertical takeoff and landing and can land on slopes of up to 15 degrees, with indications that landings on greater slopes are possible.[26] Also, in the late 1980s, a Canadian firm built a remotely piloted helicopter capable of horizontal speeds up to 80 miles per hour, altitudes up to 10,000 feet, and hovering maneuvers.[27] The vertical takeoff and landing capability of these types of vehicles reduces the space required for cargo unloading (and loading during extraction operations) and allows landing at unimproved sites, which gives much more flexibility to the war fighter in placing troops and equipment. Because of this almost unlimited capability to place troops where and when required, the US can retain or achieve the advantage of surprise, at least until the UAVs are deployed from the mother ship and potentially until they are making their final approach at the landing site.

Among the drawbacks to the use of helicopters are that they generally require more power than equivalent fixed wing aircraft and are adversely affected by high altitudes and hot temperatures. Significant advances in propulsion design and fuels would be required to solve or at least minimize this problem. Helicopter UAVs are also more complex but the use of adaptive neural networks could eventually be used to control these types of vehicles.[28] Also, although helicopter UAVs currently have limited maneuverability, genetic algorithm could be useful in increasing their maneuverability enough for effective use in an airlift role in a hostile environment.

The final disadvantage of unmanned helicopter vehicles in the airlift role is that their in-flight performance is significantly less than conventional fixed-wing aircraft. A solution to this is the development of an x-wing or "stopped-rotor" type of aircraft. This design combines the vertical takeoff and landing characteristics of a helicopter-type vehicle with the forward speed of a conventional fixed-wing aircraft. A rotor would be used to enable vertical takeoffs and landings and then would be stopped in flight to serve as wings for forward flight at speeds in the high subsonic region.[29]

As mentioned, x-wings retain the vertical takeoff and landing characteristics that are necessary for maximum flexibility in the direct delivery and extraction of cargo and personnel to and from the battlefield. The capability to transition to forward flight would allow greater forward speed, potentially into the high-subsonic range, which would enhance the survivability of the aircraft in a hostile environment since it is harder to hit a fast-moving target.[30] Also, this capability to transition to forward flight would increase the vehicle's range and would enable the mother ship to remain farther from the battlefield without delaying the time required to deploy a unit to the field. Like the helicopter UAV, the x-wing design would incorporate fully autonomous flight control and navigation using an internal miniature inertial navigation device preprogrammed by the airlifter flight crew, and would be capable of landing and taking off from an unimproved site. Among the disadvantages of x-wing UAVs are the difficulties in overcoming the transition from rotors to fixed wings and the development of an appropriate powerplant that could provide power to the rotor as well as supply thrust for fixed-winged flight. While these challenges were being addressed as early as the late 1980s, technological advances in propulsion, as well as in

circulation control for the critical transition phase between rotor-powered flight and fixed-wing flight, should enable the use of an x-wing unmanned vehicle by the year 2025.[31]

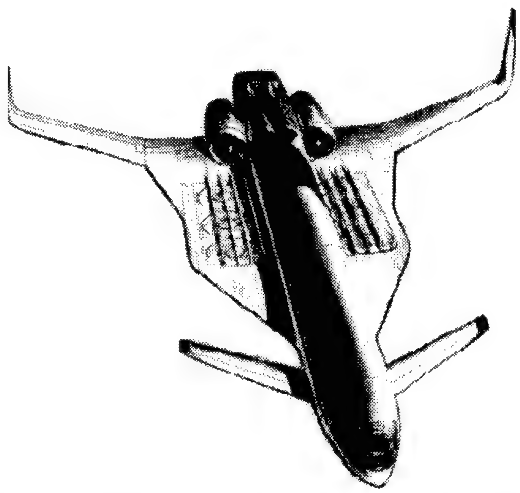


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Figure 3-5. NAL Jump Jet

A similar and perhaps more promising aircraft is another vertical takeoff and landing vehicle capable of forward flight, the so-called jump jet or hoverjet being developed by the National Aerospace Laboratory (NAL) in Tokyo (fig. 3-5). The design of this transport helps ensure stability in the low, forward-speed range and during vertical flight and is powered by three aft-mounted turbine engines that power a unique system of lift fans and cruise fans. During forward flight, the air trapped from the compressors would be routed to two cruise fans. For vertical flight, this same high-pressure bleed air would be routed to six rotors, made of single piece carbon fiber composites, encased in the wings and shielded by louvers on both the upper and lower sides. The transition from vertical to horizontal flight is accomplished by gradually redirecting the air from the rotors to the cruise fans.[32]

Although this particular vehicle is designed to transport more than 100 passengers at 0.8 Mach with a range of 1,600 miles, the basic technology could be converted into an unmanned aircraft that could be launched and recovered from a much larger mother ship as discussed in the preceding paragraphs. One of the biggest design challenges for NAL has been the development of a powerful and reliable lift fan. In addition to advances in power plant design, the success of aircraft of this type also depends on advances in composite materials and manufacturing processes. Even more than the previously mentioned UAV designs, this hoverjet would require significant progress in adaptive neural networks and genetic algorithms to achieve autonomous control of the vehicle. Finally, since cargo containers would be carried inside the aircraft instead of being slung beneath it like the helicopter and x-wing UAVs, this type aircraft would require some type of material handling equipment to off-load or onload equipment.

The "jump jet" design, however, offers some advantages that the helicopter and x-wing UAVs do not. Like them, this aircraft takes advantage of both vertical and horizontal flight. Its size and design would be attractive to the commercial market where it could be used in the short-range passenger market as well as short-haul cargo routes. Major disadvantages, in addition to the requirement for on-board cargo handling equipment, are the increased infrared signatures resulting from the high heat and pressure generated from the engine compressors and the fact that this type of design would probably be much more expensive than the previous two, resulting in fewer overall numbers and a greater reluctance to send it into a hostile fire zone.

A potentially less expensive airlift UAV would be an ornithographic vehicle—an engine-powered aircraft that flies by flapping its wings. The world's first successful engine-driven ornithopter flew in September

1991 for a grand total of two minutes and 46 seconds.[33] While this vehicle was not large (only four kilograms and a three meter wingspan), it did achieve flight and demonstrated this method of propulsion does work. The creators of this modern-day Icarus believed they could build an ornithopter that could carry a single person by 1996.[34] With advances in propulsion systems and lightweight but strong materials, a UAV could be designed that would be no more than a frame with a power plant and wings with a generic attachment for a cargo container. The powered wings would allow for a controlled glide to the unimproved landing zone, adjusting for winds and avoiding detected threats. The wings would also enable a "soft" landing in a small area by rotating into the wind just above the ground in the same manner as birds alighting on a nest or a tree limb. A design of this type would provide an additional measure of stealth since the use of flapping wings would be significantly quieter than a rotor-equipped vehicle. Also, if the wing materials were inexpensive enough and the power plant and control package were small, the UAV could be virtually disposable on the battlefield. (Containers would also have to be disposable or useable by the war fighter.) Additional technologies such as very short-term (within days), biodegradable materials would enhance the disposability and help prevent discovery of personnel operating in a covert mode. This capability would be greatly beneficial to special operations personnel or any other unit operating in a covert mode in hostile territory and not wanting their operations revealed by the presence of a delivery vehicle.

An obvious disadvantage of an ornithopter UAV would be the inability to lift large, heavy containers without revolutionary breakthroughs in propulsion, materials, and aeronautical design. Without the capability of lifting large, heavy containers, another vehicle would be necessary to provide the direct extraction of cargo and personnel. These powered vehicles, however, would be more expensive to develop and operate than ornithopters. Since retrograde often occurs at a much lower rate than deployment, ornithopters (or other unpowered vehicles) and powered lifting vehicles could be used in conjunction (at a ratio of three unpowered UAVs per powered UAV) for less cost. Another disadvantage is that this type of flapping wing design would be relatively slow moving, exposing the vehicle to enemy fire longer and allowing for an easier targeting solution for the enemy. This disadvantage however, could be overcome by employing other stealth technologies in the design (i.e., stealthy materials, a cloaking mechanism, etc.).

A more feasible delivery vehicle would be based on the "Angel's Wings" concept developed for the Army by Dr Lowell Wood. The original concept would be implemented as a helicopter-type personal lift device individuals would be able to strap on. With auto-folding and unfolding composite rotating wings, a GPS-updated microprocessor, and a 50-horsepower internal combustion engine, this device would be able to deliver the twenty-first century warrior to the battlefield in an unpowered mode, using flywheel energy to provide last-minute braking. Liftoff would be provided either from the energy stored in the flywheel (modern flywheels have the capability to store enough energy to lift their own mass up to 10,000 kilometers) or from the 15,000 revolutions per minute engine. Although designed for only one person, increasing the swept-circle diameter of the rotating wings as well as increasing the engine thrust would provide capability to lift much heavier payloads.[35]

Delivery vehicles of this type are relatively simple, allow rapid retrograde, and provide significant mobility across the terrain for ground forces. With the engine shrouded and using ducted fan-cooling design, the vehicle and payload would have minimal signatures across the spectrum. Disadvantages include the size of the rotating

wings to lift heavy payloads and the resulting increase in platform signatures. It is doubtful the useful payloads could be increased to provide enough lift capability without having to use a significant number of vehicles or increase the platform signatures beyond acceptable levels. If used as an individual lift device, the soldier would need some sort of protection from the elements particularly if deployed from a mother ship located 100 to 200 miles from the battlefield. Finally, the speed of these vehicles would be relatively slow, which would increase their exposure to hostile fire. The concept in its current form is available using commercial off-the-shelf components and technologies. However, to decrease weight and reduce detection signatures while increasing range and lift capacity, advances in structural composites, engine design (to include minimizing noise output), as well as in microminiaturization of communications, sensors, and navigation packages are required.

Other potential delivery vehicles are ballistic and cruise missiles. Ballistic missiles have the capability to provide the most rapid in-transit delivery vehicle for small, high-priority payloads, can be configured to ensure payload survivability and extreme accuracy, and are technologically feasible. However, there are many negative aspects to consider. First, the delivery system resembles the delivery characteristics of weapons of mass destruction. Since ballistic missile designers are developing capabilities to alter in-transit flight profiles to counter antiballistic missile systems, any flight profile that vaguely threatens potential enemies could provoke a preemptive strike against what is in reality a cargo transfer. Not only could this system destabilize a developing crisis, it would also result in the loss of a high-priority payload that was important enough to get to the user extremely quickly. Also, ballistic missiles have high profiles that could eliminate the element of surprise for most payloads. In addition, the cost of expendable launch vehicles is extremely high and few payloads, except for highly critical ones, would warrant such costs. The system would also require the retention of a complete weapon system support infrastructure to support a small quantity of payloads. Furthermore, the infrastructure for ballistic missile launch does not coincide with the logistics support infrastructure, requiring payloads to be delivered to remote launch facilities, incurring additional time for transit from point of origin to point of embarkation.

Cruise missiles can transfer 500-pound payloads over 1,500 miles while maintaining a low-observable profile, autonomous control, and precise point of delivery. With development of containers for supporting diverse cargoes, cruise missiles can be developed to rapidly deliver payloads to users without reliance on infrastructure between points of origin and delivery. Evolutionary changes such as improvements in composites to strengthen airframes while reducing weight, increasing engine efficiencies and output, and using low observables technology to decrease probability of detection, can improve range, payload, and mission effectiveness. With development of the capability to recover cruise missiles used for cargo delivery in a mission-capable condition and to ensure proper en route identification, cruise missiles can provide direct delivery and extraction support for cargoes meeting weight and volume constraints. This capability is significant in high threat environments and operations in niche theaters such as support of forces ashore by naval units in littoral areas. Operating as an autonomous UAV, the cruise missile provides a lower cost, less vulnerable platform than most airlift vehicles. The main problems with cruise missiles are significant volume and weight constraints, differentiation between strike and airlift cruise missile operations by friendly, neutral, and hostile forces, and constraints on making changes to cargo while en route.

Due to its capabilities, the cruise missile provides a possible component of the overall airlift system, but its limitations constrain its useable mission profiles and the amount of cargo that could be delivered.

Additional Equipment

Equipment that is not platform specific but which is required for the mobility system of 2025 includes cargo containers and onboard materiel-handling equipment. Additional equipment/subsystems such as robust communications, targeting computing, stealth/low observables, and so forth, are not airlift specific and should be the same systems that are used on other aerospace platforms.

Cargo Containers

Containers will be standardized between US military and commercial aircraft and will also comply with international standards to improve compatibility with potential allies and coalition partners. Modular units, such as those used for medical evacuation units, will use these standard-size cargo containers without modification in size and/or dimensions to enable transport via the most effective means, regardless of whether it is by aircraft, ship, railroad car, or truck. Use of these standardized containers, miniaturization of many components and weapons, and the possible transition from projectiles to directed energy weapons will result in less weight and volume to be transported to the theater and will eliminate most, if not all, of the current air cargo categories such as oversize and outsize.

In addition to ease of handling during transshipment, standardized containers will provide protection during climatic extremes, allow information about the internal contents to be transmitted to the user, allow for quick download at destination (in minutes), all while not generating disposal problems in either a peacetime or wartime environment.[36] If made of strong lightweight materials that are fire retardant, vermin-resistant, and waterproof, the containers will be able to provide the protection required without adding significant weight to the payload carried by the delivery vehicles and the mother ship. The containers must also allow extremely rapid unloading (within a minute or less) if delivery into a hostile zone is required. Finally, the containers must be built to allow the attachment of delivery vehicles (either powered or unpowered) to form an integral unit and eliminate the problems of slung loads.

Onboard Materiel-Handling Equipment

The cargo bay of the "mother ship" must have some robotics-based, materiel-handling equipment capable of shifting the cargo containers and other equipment while in flight to ensure the center of gravity is maintained within flight limits, as well as optimizing personnel and equipment for rapid offload at the destination. This robotic system will be controlled by the flight crew through the onboard computer systems and will act semi-autonomously. Payload configuration systems will analyze payload and mission profiles to configure the payload to maximize volume and mass, minimize airlift system operational requirements, and facilitate cargo upload and download needs.

Recommendations

The Scientific Advisory Board has recommended five primary areas for airlift system improvement: mobility information dominance, global range transports, precision guided airdrop, directed energy defensive systems, and virtual reality military applications.[37] However, as discussed earlier, additional considerations are necessary and include the need for direct delivery *and* extraction and the ability to operate in hostile, infrastructure-deficient environments.

Each of the systems described above were evaluated for their ability to provide the capabilities required in 2025 that were discussed earlier in this paper. Since one of the major assumptions of this paper is that the air mobility system will not have access to airfields outside of the CONUS, the system chosen must have an extremely long range and be capable of direct delivery and extraction. The system must also be survivable in a hostile environment and be responsive to the customer's needs by getting all the user's personnel and equipment to the required location in time to accomplish the war fighter's mission. Because some of the alternate futures postulate significant to severe budget restrictions, the platform must not be cost prohibitive. Other capabilities required in 2025 such as Total Resource Visibility, intermodality, modularity, and interoperability, are not platform dependent but must be included in whatever platform is selected. A review of the evaluated systems and their contributions to the air mobility system of 2025 is shown in table 2.

When the described systems are compared against the capabilities required by the air mobility system of 2025, airships, used in conjunction with unpowered and powered UAV delivery platforms (primarily vertical takeoff and landing or VTOL vehicles), are the best matches for the air mobility system of 2025. Although the airship is not as fast as modern jet aircraft, its high-cargo capacity (both in weight and volume) allows the delivery of more materiel to the battlefield sooner than a much larger and more expensive fleet of jet aircraft, ultimately supporting the war fighter sooner than today's air mobility system. Additionally, the standoff capability of the airship/UAV system provides much greater survivability than existing and proposed systems. A fleet of C-17s will still be in the Air Force inventory and will be able to provide the same precision delivery capability for small, light forces using the described delivery systems. If transshipment bases are available in or near the theater of operations, the C-17 can also be used to support intratheater lift. Direct extraction capability will be provided by the combination of the VTOL UAV and the airship. Chapter 4 describes how these futuristic air mobility systems will operate.

Table 2
Summary of System Options

	Point of Use Delivery	Direct Extract	Range	Speed	Required Infrastructure	Required Tech	Capacity
TAVs	Low[a]	Low[a]	Global	Very High	Very High	Very High	Low
Supersonic Transport	Low[a]	Low[a]	Moderate	Very High	Very High	High	Moderate to High
Airship	High	High	Very High	Low	Low	Low	High
Wing-in-Ground Effect	Very Low[b]	Very Low[b]	High	Moderate	Moderate	Very high	Very high
Very Large Aircraft	Moderate	Moderate	Global	Moderate	High	High	Very High
Parafoils	High	None	Low	Low	None	Low	Moderate
Helicopters	High	High	Moderate	Moderate	None	Low	Moderate
X-wing	High	High	Moderate	Moderate	None	High	Moderate
Jump Jet	High	High	Moderate	Moderate	None	High	Moderate
Ornithopter	High	High	Low	Low	None	Very High	Low
Ballistic Missiles	High	None[c]	High	High	Moderate[c]	Low	Very Low
Cruise Missiles	High	None[c]	High	High	Low[c]	Low	Very Low
Angel's Wings	High	Moderate[d]	Low	Low	None	Low	Moderate to Low

[a]Deployment/recovery of containers from/to extremely high speed aircraft is improbable.
[b]Only if point of use is port or beachhead.
[c]Would require launch structure in field and additional recovery apparatus on mother ship.
[d]Powered altitude capability unknown.

Notes

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Chapter 4

Concept Of Operations

No matter how futuristic or innovative weapon systems may be, they will be of little or no use if they adhere to yesterday's operational concepts. The following concept of operations using the systems mix recommended in chapter 3 represents what we believe to be a revolution in systems use and operations that will exponentially increase the efficiency of the war fighters in 2025.

The basic mission, goals, and objectives of air mobility will likely remain as they are today. The airlift operational tasks of cargo airlift, passenger airlift, aeromedical evacuation, and special operations airlift will continue. The core support processes of information resources management, C^4I systems, information warfare, intelligence, logistics, training, security, operations support, medical, cargo and passenger handling, and base operating support will be crucial.[1] However, new technical and operational parameters will change the look of airlift platforms. Air cargo in 2025 will no longer be categorized as bulk, oversize, outsize, rolling stock, and special, as standardized cargo containers are integrated into the airlift system.

The future air mobility system will utilize both commercial and military resources to execute the missions of 2025. Future worldwide commercial infrastructure may be able to handle a large portion of the routine airlift requirements but will be unable to provide military unique requirements. The military airlift system will be able to overlay on the commercial system to provide direct delivery and extraction from unimproved and remote areas, the capability to operate in hostile environments, and the extreme range required to operate around the world solely from bases located in the continental United States. This overlay will be seamless, using standardized cargo containers as well as a total resource visibility system to provide interoperability between commercial and military airlift platforms. As previously described, the air mobility system will include both the C-17 and long-range airships as strategic lift platforms, and both unpowered UAVs (primarily parafoils attached to cargo containers) and small powered UAVs as delivery vehicles. The Civil Reserve Air Fleet will still be used in 2025 to complement organic passenger and cargo capabilities.

The described TRV system, part of the DOD-wide logistic system, will identify and track cargo and personnel from origin to final destination and return. This system will have the capability to notify simultaneously the transportation system and the supported unit. The required transportation assets will be automatically generated by the same system once timing and flow decisions have been directed by the NCA. The large airlifter will deploy with sufficient parafoil delivery systems and powered UAVs to accomplish the assigned mission. Since any type of retrograde will occur at a slower rate than deployment, there will normally be one powered UAV for every four parafoil delivery systems. (If the capability exists to manufacture biodegradable materials, the vast majority of the parafoils will be unpowered with just enough powered UAVs to support aeromedical evacuation and retrograde operations to include noncombatant evacuation operations.)

In CONUS

When a unit has been notified of an impending deployment, it will load cargo and/or personnel into standard cargo containers. These containers, in addition to

those few self-powered vehicles that can not be loaded into containers, will be moved via land to the nearest airfield (most likely a commercial airport) and loaded onto strategic lift platforms. For those forces with less than 48 hours from departure to required delivery time, C-17s will be the platform of choice. Airships will be used to directly deliver the remaining required equipment and personnel and the majority of self-powered equipment. Since the cargo containers are wheeled they will require minimal handling. Equipment no more sophisticated than that currently used (trucks, C-17 MHE) will handle remaining requirements. Self-powered equipment that is not loaded in a cargo container will have standard attachment points to enable easy loading and securing of cargo in the cargo bay of the airship.

If deployment time constraints require, the airship also will be able to embark a unit and its equipment directly from the unit's point of origin. The mother ship with UAVs (both parafoils and powered UAVs) would be flown from its home base to the pickup location where the powered UAVs would pick up the cargo containers. Once within range of the user's location, the powered UAVs would be deployed from the airship and flown to the pickup location where the containers (or self-powered equipment) will be attached to the powered UAVs by the users. Once the container or piece of equipment is attached, it will fly back to the mother ship for recovery. The cargo will be detached by the aircrew and the UAV will repeat the process for as many trips as required. If space exists on the mother ship, other units will be loaded either sequentially or simultaneously. Robotic material-handling equipment in the cargo bay of the mother ship will be able to move containers around as required to ensure the proper center of gravity is maintained and to facilitate quick offload at the various drop zones.

En Route

Throughout the en route phase of operations, users will maintain communication with their command and control components. To facilitate communication, the user's command modules will be linked to the mother ship's power and communications systems using standard connections. If a change to the final destination, payload configuration, or force package is required, the data will be passed to both the crew of the mother ship and the users on board by the appropriate command and control facilities. These updates will be entered into the system and will reflect the changes in near real time. Users will be able to interconnect with the aircraft cargo computers to input desired offload sequencing of their cargo containers and the target locations. This will enable the cargo bay robotics, as directed by the flight crew, to move containers and/or other equipment within the cargo bay to optimize offload sequencing while maintaining the required center of gravity. These robotics will also marry up the appropriate UAVs (either the parafoil assemblies or powered UAVs) to the cargo containers for offload.

Due to extended en route times, aircrew management and composition will be significantly different from those that are currently practiced. Increases in crew size (i.e., using two or more crews in sequence) and use of performance-enhancing substances are possible solutions. Personnel will also be required to assist the robotics and provide necessary maintenance. Crew work/rest cycles will require sleep facilities on board the aircraft for the entire crew.

In-Theater

Once in the theater of operations, two options exist for delivering personnel and equipment. If intratheater bases are available (as well as in-theater transportation), the airship or other aircraft (e.g., C-17, CRAF vehicles, etc.) can land and off-load. If the intratheater bases are not

available or the cargo must be delivered quickly to the battlefield, the personnel and equipment can be delivered directly to the desired location using the guided parafoil delivery systems. Immediately before their release, the airlifter cargo crew will ensure the guidance packages are programmed with the desired drop zone locations, known winds, and threat areas to be avoided, and other data necessary to ensure they arrive at the target location.

The parafoils (and other powered UAVs) will be released/deployed once the airlifter is within range of the drop zone. Once released, the UAVs will guide themselves to within 10 meters of the target. The containers, which have been configured by the users to enable expeditious unpacking at the drop zone, will be unloaded by the users. If the parafoils or cargo containers were not biodegradable or for other reasons required return to the airlifter, the powered UAVs will be used. Once en route to the airship, the UAVs will request and receive a burst transmission from the airlifter giving it return instructions and locations. The powered UAV would fly back to the airship and directly into the cargo area. Due to the high-operational risk, particularly when recovering personnel, the process will incorporate some degree of human intervention either via remote control of the UAV by an aircrew member or through positive control of the UAV/robotic recovery system. Once aboard, the contents of the containers will be unloaded by the cargo bay crew who, with the help of the robotic system, will recycle systems as required for future use. The airship would either remain in place to continue delivery and reception operations or proceed to the next drop zone as required. Since the C-17 will be able to deliver a significantly smaller amount of cargo, it will usually service a single location and then either return to CONUS or recover at an intratheater base if available.

Special operations requires airlift support for insertion and extraction of operational forces and equipment. The airlift system components are capable of supporting special operations requirements. However, the VTOL airlift vehicle must incorporate sufficient low-observable profiles to both active and passive detection to lower the probability of detection and interception to levels sufficient to allow mission effectiveness. The standard VTOL airlift vehicle will incorporate low-observables technology within resource constraints. In addition to these technologies, the special operations VTOL airlifter will incorporate active and passive offensive and defensive systems to support mission needs. It is important to note that these systems will not require development of a unique airframe or substantial infrastructure to support special operations needs.

Once all personnel and equipment have been delivered, the airship will remain in an orbit area to recover casualties and/or remove the inserted forces. If the duration of the operation were to exceed 48 hours, the airship would begin the return trip to CONUS only after being replaced by another airship with aeromedical evacuation capability.

Aeromedical Evacuation

Medical evacuation in the year 2025 will use the same airship platform that is used for transporting cargo and personnel. Before departure from its CONUS base, one or more portable, modular medical units will be loaded into the airlifter's cargo space. These units will contain medical supplies and life support equipment as needed to care for expected casualties for the duration of the flight to and from home station. The appropriate types and number of medical technicians deemed necessary will accompany the medical units and remain with the airlifter. These medics will be in addition to any field medics that may be deploying with the ground units. In addition, a small number of cargo containers will be designated solely for the evacuation of battlefield casualties. These vehicles will be equipped with either

autonomous life-support systems much like the neonatal units in use today (although significantly larger) or will provide seating for one or more medical technicians to care for the evacuees.[2]

Launch and recovery of these medical units would be in the same manner as delivering or extracting cargo and personnel, and would provide relatively quick transportation of casualties from the battlefield to a place where long-term care is available. No special medical equipment other than the autonomous life-support systems and medical supplies would be required for these units since transport time should be relatively brief. Most care could take place on board the mother ship (in the modular units) with the medical technicians using communications links with CONUS to consult appropriate experts. On return to home base, patients would be off-loaded either by stretcher or within the modular units themselves. While this concept of operations increases the turn time at home station and decreases the amount of cargo and personnel deployed to and from the battlefield, it deletes the requirement for an additional airlifter and uses all of the same components of the cargo and personnel delivery system. It also removes casualties from the battlefield as soon as they can be placed into the dedicated medical UAVs and airlifted directly to the modular medical units on board the airlifter, reducing complications and resulting in decreased morbidity and mortality rates.

Survivability

Because commercial airlift operations do not incorporate the offensive and defensive systems necessary to survive in a high-threat environment, airlift operations will require military aircraft to support requirements in hostile areas. Expected threats include ground, sea, and air launched missiles as well as enemy attack aircraft. To counter these, military airlift platforms should be configured with directed energy weapons coupled to multispectral sensor packages enhanced with state of the art computational capability. With the proliferation of threat technology, these platforms could provide an offensive capability to employ weapon systems for operations ranging from rear area sustainment in a low-threat environment to operational power projection in high-threat environments. Possible offensive capabilities include standoff aerial bombardment and the employment of combat UAVs in support of ground operations.

Many missions, such as diplomatic and humanitarian assistance, may require airlift platform configurations lacking active offensive and defensive weapon systems. Therefore, the airlift platform must be configurable to support these missions as well. Modular weapon system packages will provide this system flexibility and will enable the employment of the airlift platform throughout the spectrum of conflict.

Presence

Military airlift platforms directly support power projection and presence.

> When this nation responds, mobility forces are no longer merely support forces. We use these aircraft to project influence. When those aircraft are sitting on a ramp in some far away country with that American flag on the tail they are not representing the United States of America, they are the United States of America.[3]

When the government wishes to de-emphasize involvement, commercial carriers are acceptable unless payload prohibits their use. Because official United States aircraft reflect national commitment and power, military airlift platforms provide political dividends that can exceed the benefits of cost savings achieved through commercial carriers. The media does not turn out to highlight commercial cargo but even one military transport can gain global attention when properly managed. "Media coverage of any future wars will by necessity weigh heavily in determining the level of national resolve, the degree of commitment, and the complexion of the response. . . . As

the old adage goes, 'pictures don't lie,' and quite literally they speak louder than words."[4]

Special-Handling Requirements

The military airlift network also transports payloads requiring special security and/or special-handling requirements. These payloads include: high-profile dignitaries, weapons of mass destruction, research, developmental test and evaluation materiel, hazardous materiel, equipment supporting compartmentalized operations, and international assistance programs. These operations support the military, other governmental agencies, and foreign governments. Additionally, oversized payloads, security, hazardous material, environmental control cargo requirements, and special-handling needs may also arise. Although many of these activities may be supported by commercial carriers if proper measures are implemented, the potential loss of control, conflicts of interest, security aspects, and political effects will make retention of military airlift support preferable.

The melding of airships and UAVs with the concept of operations recommended above will enhance the entire spectrum of air mobility operations. Most importantly, the revolutionary point-of-use delivery and extraction capabilities will enable the war fighter to aggressively and decisively prosecute the field of battle. Additionally, this concept shows potential for use by the commercial sector to enhance the cost effectiveness of cargo movement.

Notes

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Chapter 5

Conclusion

The realization of an air mobility system as extensive as that recommended in this paper demands the development and integration of a wide range of technologies (table 3). With the exception of low visibility enhancement and directed energy, each of the above technologies is currently being developed and validated in the commercial sector. Because of this, and given the continued paucity of defense research and development funding, we believe it is necessary that any new air mobility system evolve from the application of civilian technologies to the problem of airlift. Conversely, any system conceived and implemented by the military would ideally have some commercial applicability. If the military could demonstrate the technological feasibility of a concept and the civilian sector could demonstrate the feasibility of commercial applications of that technology, both sectors would benefit from the operation of common systems and any complementary infrastructure. This close cooperation would also enhance air mobility operations by providing sufficient resources to the commercial market for inclusion in a future version of the CRAF.

The physical aspects of the air mobility system recommended in this paper are evolutionary. It proposes systems that, with a modicum of technological development, could be in service by 2025. The concept of operations proposed for the air mobility system of 2025 is, however, revolutionary. It represents the application of technology to the capabilities we believe will be required to meet the logistics needs of our military at that time. These capabilities include responsiveness, point-of-use delivery, direct extraction from point of use, interoperability, intermodality, survivability, and long unrefueled range. While some of these activities are possible today, they are not performed at the level and with the consistency that must exist in 2025.

For the concepts proposed in this paper to become a reality, two events must occur. First, the ever widening gap between airlift requirements and airlift capability must be acknowledged. Advanced war-fighting systems are of little utility if the warrior is unable to sustain, or even join, the fight. Second, emphasis must be placed on those systems that best solve the problems future conflicts present. Adherence to the adaptation of archaic systems and ideas to the problems of the future (as the French did before World War II) only serve to delay the inevitable: the catastrophic failure of a system in the face of requirements it was never capable of addressing.

The systems presented in this paper address our future air mobility concerns. It is our hope that what we propose will stimulate a debate that will lead to the development of innovative solutions to the air mobility problems before us.

Table 3
Required Technologies

System	Technology	Advantage
Airframe	*Lightweight Materials	Lighter Weight, Higher Useable Lift Stronger Structures
	*Composites	Lighter Weight, Higher Useable Lift Stronger Structures
	Nanotechnology	Self Repair Expanded Environmental Operating Parameters Light Weight/Small Components
	Boundary Layer Control	Higher Speed Greater Fuel Efficiency
	Articulating Design	Allows Use in High Wind Gusts
Power Plants	*Ceramics/Metallurgy	Allow Higher Temperatures at Lighter Weights Greater Thrust
	*Advanced Fuels	Greater Efficiency
Aircraft Control	*Computer Processing	Maintenance of Weight and Balance During On- and Off-load Operations Wind Gust Control *Endanced Semi Autonomous Control
	Nanotechnology	Self Repair
	*Microinertial Navigation Systems	Reduction of Weight and Space
	Lift Gas Processing	Pressure Stabilization throughout Flight Regime
Materiel Handling Equipment	Robotics	Reduced Crew Workload
	Composites/Metallury	Lighter, Stronger Structures
Survivability	*Multispectral Sensors (w/enhanced computer processing)	Early Identification of Threats *All Weather Operations
	Directed Energy (w/enhanced computer processing)	Defense against Threats
Total Resource Visibility	Computer Processing	Allow Near-Real-Time Updates to Command and Control Elements
	Communications across Known Electromagnetic Spectrum	Communications Security Simultaneous Access for Multiple Users

*Applicable to UAVs

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Spacelift 2025: The Supporting Pillar for Space Superiority

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Executive Summary

The US spacelift system in 2025 focuses on routine operations. The research and development (R&D) mentality of past spacelift programs is replaced by the aircraft-like operations of a fully reusable spacelift system, operated by both commercial industry and a US spacelift wing. Though developed primarily as a practical and affordable alternative for orbital access, the multipurpose transatmospheric vehicle (MTV) is expanded into force-enhancing missions like intelligence, surveillance, and reconnaissance (ISR), global mobility, and strike. MTV becomes the strategic strike platform of 2025. It can be flown manned or unmanned, depending on mission requirements, but it is primarily used in the unmanned mode. With the capability to accomplish the earth-to-orbit (ETO) mission as well as these other earth-to-earth (ETE) missions efficiently, the MTV is a flexible platform which strengthens all air- and space-core competencies. MTV is complemented by the orbital transfer vehicle (OTV) for space orbital missions. After MTVs park satellites in low orbits, OTVs provide the additional thrust needed to push the payloads into higher energy orbits. OTVs also facilitate the maintenance of satellites in orbit by retrieving existing platforms for repair, refueling, or rearming. Finally, OTVs give the spacelift system a rapid orbital sortie capability for deterrence, space control, reconnaissance, counterspace, and force application.

This paper recommends Air Force support for NASA's X-33 transatmospheric reusability demonstration and investment in a follow-on military MTV and an initial OTV using today's technologies. Once routine operations are institutionalized with these first generation reusable systems, propulsion and material technology should be infused to provide a more capable system. This paper recommends avid support of R&D funding needed to provide these technological advances. The technology push should not end with the initial incorporation of advanced propulsion and lightweight materials into second generation systems, as third generation revolutionary concepts like fusion and antimatter promise even greater capability. Finally, the paper recommends development of innovative missions for the 2025 spacelift system which enable it to strengthen all air-and space-core competencies. The incremental approach outlined in this paper provides the best opportunity to field an operable system which supports all customers.

Chapter 1

Introduction

Space started in an R&D mode; it has difficulty moving to an operational mode.

—Gen Ronald R. Fogelman, CSAF

Spacelift is the key supporting pillar of the space superiority core competency. Without the support of spacelift, other platforms do not make it into orbit to execute space superiority operations. Space superiority, along with global mobility, information dominance, air superiority, and precision employment, are the US air- and space-core competencies.[1] Since losing spacelift capability would have a devastating effect on US ability to achieve space superiority, spacelift is the strategic center of gravity for all space operations. Moreover, spacelift in the year 2025 is more than just a critical supporting pillar for space superiority, because affordable, reusable spacelift also is an effective force enhancer for the other air- and space-core competencies.

The focal concept of spacelift in the year 2025 is routine operations to, through, and in space. The 1994 *Space Launch Modernization Plan* advocates a shift away from a "launch" mentality to an "operations" mentality.[2] This operations mentality is vital to building a twenty-first century space architecture, which the Air Force's *New World Vistas* study envisions as a survivable, on-demand, real-time, global presence that is affordable.[3] Without affordable access to space, the rest of the space missions are difficult to accomplish. There simply is not enough funding available to develop innovative space-based capabilities while continuing to employ brute force methods of getting to orbit. Routine operations are more affordable, because they eliminate the large standing armies required by the research and development (R&D) processing philosophy of current expendable systems. Affordability can be improved further through the infusion of revolutionary, evolutionary, and commercial advances in technology, particularly propulsion and materials. These advances lead to reusable, single stage to orbit (SSTO) spacelift vehicles, capable of satisfying all spacelift requirements. These vehicles allow aircraft- like routine operations to occur in spacelift.

In the year 2025, spacelift is the conduit to the "high ground" of civil, defense, and commercial space operations. To maximize the operational advantages of space, the US has established a composite spacelift wing composed of vertically launched, SSTO, fully reusable, and maintainable multipurpose transatmospheric vehicles (MTV). These MTVs responsively deliver light-to-medium payloads into and through low earth orbit (LEO). In addition, the Department of Defense (DOD) maintains a squadron of orbital transfer vehicles (OTV), attached to the international space station infrastructure. These are employed to move satellites between orbits, thus minimizing initial lift requirements for the MTVs. OTVs also add life to satellites by refueling, rearming, and resupplying them, as well as protecting the US space architecture. This MTV/OTV combination provides any theater with rapid response, all-weather surveillance, and sortie capabilities in less than an hour.

Heavy lift is a joint government and private commercial venture for scientific and commercial purposes with military mission augmentation capabilities. To expand scientific knowledge and economic

opportunity, NASA, DOD, and private industry pursue intersolar system exploration as a joint international venture. DOD is the space traffic control manager. They also lead the international planetary defense system (IPDS) and operate a directorate on board the space station. In the commercial sector, spacelift ventures are based on average launches per day and safety records comparable to the airline industry of the 1990s.

Using a flattened organization with technician-level maintenance, spacelift operations are routine. Space launch corporations have transformed several closed Air Force bases into space ports. The remoteness of these bases provide added safety buffer zones. Advances in computer diagnostics provide real-time, on-the-pad systems checks with self-repair and automated rerouting of vital space vehicle functions. Seeking to protect and modernize their space architecture, some nations and multinational corporations pursue the space debris environmental cleanup, which is a multimillion dollar business. Space-based antisatellite weapons, antiballistic missile weapons, and precision guided munitions (PGM), including lasers, particle beams, kinetic weapons, and nonlethal weapons, are the DOD's primary arsenal for space control and force application deployed from standardized modular packages. MTVs contribute to global mobility by inserting small, highly equipped, armed teams of the US Space Special Operations Forces or critical cargo anywhere on the globe through LEO. Air Force global reach is felt anywhere in the world in less than an hour.[4] Intelligence, surveillance, and reconnaissance (ISR) and capable MTVs provide almost immediate situation awareness of any trouble spot, and strike-configured MTVs add force application capability. The US Spacelift Wing is the primary deterrent force of 2025.

The above spacelift concept in the year 2025 is derived using the horizon mission methodology, which channels creative thinking by envisioning missions and desired architecture in the future then projects them backward toward the present to provide the evolutionary and revolutionary progress needed to achieve that future.[5] Using this methodology, the key attributes of the 2025 spacelift system are routine operations with reusability, high-thrust/energy propulsion, modular mission packaging, lower mass fraction (a combination of structure materials and fuel), streamlined infrastructure, and operational simplicity. The combination of these attributes provide affordability. This paper addresses these solution characteristics, describes the spacelift system, details the concept of operations, and gives recommendations that expand the options presented in the *Space Launch Modernization Plan*, SPACECAST 2020, and *New World Vistas*. In the year 2025, routine spacelift operations into, through, and in space will strengthen air-and space-core competencies.

Notes

1. Air Force Strategy Division, *Air Force Executive Guidance*, Office of the Secretary of the Air Force (Washington, D. C.: Government Printing Office [GPO], 1995), 2.

2. Under Secretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy (Washington, D. C.: GPO, 1995), Executive Summary, 14–17.

3. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), i.

4. Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, ***2025*** Support area, 6 March 1996. (Secret) Information extracted is unclassified.

5. John L. Anderson, "Leaps of the Imagination Using the Horizon Mission Methodology," *Ad Astra*, January/February 1995, 37.

Chapter 2

Required Capabilities

The cost of spacecraft has come down an order of magnitude in dollars per bandwidth, during the last decade. The cost of launch is $10,000 a lb. We want $1,000 a lb.

—NASA Administrator Daniel S. Goldin

The 2025 spacelift system is a dedicated, responsive, reliable, and affordable operation that supports DOD space superiority missions. The *Air Force Executive Guidance*, December 1995 update, describes *space superiority* as a "core competency" for the future.[1] The 2025 spacelift system employs a combined concept of lift from earth-to-orbit (ETO), earth-to-earth (ETE), and space-to-space (STS) to support movement of US assets. The ETO spacelift is the routine operation of sending payloads into LEO. The ETE spacelift focuses on transferring cargo globally through space and executing global-presence missions using space as a transit medium. Finally, the STS spacelift is transferring, positioning, or maintaining payloads in orbits using a reusable orbital vehicle to operate within the space environment.

Commercial industry has driven the responsiveness of spacelift toward routine operations in 2025. Advances in computing, composite materials, and energy generation has lowered payload weight for most routine satellite requirements, spurring the proliferation of medium and light lift systems. With launch schedules measured in minutes instead of months, the commercial markets are dominated by the most capable systems and the most responsive providers. Deep space exploration, lunar economic expeditions, and space station support still require a small percentage of heavy lift capability, but this operation is performed by a combined corporate and government venture.

In 2025 power is defined by information. Information dominance is maintained through a combination of ground, air, and space sensors that feed an extensive data-fusion system. Responsive spacelift supports this system. With events transmitted at the speed of light, the response time to a global crisis is minutes. Spacelift system responsiveness is assured by assets already positioned in space and by ground-based space assets, which can be launched rapidly from several locations. The 2025 space forces are the global presence deterrent with rapid response launch capability to support a myriad of space missions, which includes space control, force application, space maintenance, counterspace, command, control, communications, computers, and intelligence (C^4I), and research. These assets include planetary defense and intersolar system travel. In the ETE mode, any global point must be accessible from CONUS base in less than an hour.

The 2025 spacelift system is characterized by reusability, high-thrust/energy propulsion, modular mission packaging, economically designed mass fraction, streamlined infrastructure, and operational simplicity. The above solution characteristics, coupled with routine sortie operations, drive the affordability of placing a payload into orbit. With the resulting lower cost per pound to orbit, market demands for exploiting the medium increase. This in turn drives costs even lower. Once the system demonstrates affordable spacelift, innovative ETE missions are pursued. The following are expansions of the above solution characteristics, starting with some definitions.

Definitions

Specific Impulse (I_{SP}): the standard measure of propulsion efficiency. Simply defined, I_{SP} is the number of seconds a pound of propellant produces a pound of thrust.[2] I_{SP} is a measure of fuel efficiency for comparing propulsion systems, similar to octane measurements for automotive gasoline.

Mass Fraction: In this paper, mass fraction refers to that portion of the vehicle weight that is propellant (propellant mass fraction).

Cryogenics: Liquid hydrogen and liquid oxygen propulsion systems common to many current spacelift systems, including the space shuttle and the Centaur upper stage. Cryogenic propellants must be kept cold to remain in a liquid state. This complicates the storage and operations. However, cryogenics are much more environmentally friendly than other current chemical propellant alternatives.

Generations: A method used in this paper to identifying broadly system characteristics that relate to capabilities instead of time. The three generations of spacelift in this paper are:

- First Generation: initial operable system based on current technology;
- Second Generation: first generation modified and infused with propulsion and material technology currently in development; and
- Third Generation: second generation upgraded with revolutionary propulsion system.

Margin: The portion of systems performance that remains unused and is kept in reserve to ensure reliability. Current spacelift systems leave little margin. Propulsion systems are pushed to their maximum. This is analogous to driving a car at maximum revolutions per minute all the time. With the high cost of expendable spacelift, users want to use the largest possible payload, so only minimum safety margin is maintained. By running the propulsion system below its maximum and thus maintaining margin, maintenance is reduced, reliability is increased, and costs are decreased.

Reusability

Reusability in 2025 refers to routine aircraft-like operations. The system does not require standing armies of engineers to check and double check each system prior to a launch. Instead, MTVs and OTVs are flown and reflown with minimal maintenance between most missions.

The concept of a reusable vehicle is not new. The shuttle's original premise was complete reusability, but its ballooned infrastructure, zero-defect safety requirements, and R&D processing mentality prevented its use in the truly routine operational sense. One of the main tenets of the X-33 space plane is proving the operational reusability concept.[3] The *Space Launch Modernization Plan* states that solving current technology limitations are critical. These limitations include excessive reliability/failure demands, large infrastructure costs, and the lack of institutionalized launch program oriented towards standardized requirements, metrics, and goals.[4] Further, the *President's National Space Transportation Policy* demonstrates the complementary nature of the reusability concept with military requirements. This includes vehicles maintained in "flight readiness-style," incorporated autonomous diagnostic design, flight vehicle support, ground support facilities, support logistics controlled by automatic interactive scheduling, and "airplane-like" operations. This pattern results in short turnaround with comparable safety requirements.[5]

Another advantage of reusability is increased responsiveness. The 2025 spacelift system is responsive in minutes with a fleet of MTVs continuously ready for launch missions. The MTV fleet is supported by a technician-based preventive maintenance system, with planned periodic

overhauls for modernization. Advances in computer capabilities and artificial intelligence provide real-time and on-the-fly diagnostics and automated systems rerouting, while improvements in high temperature thermal conductors and fiber optics integration reduce power requirements. Innovative thermal and radiation protection extend product life cycles, allowing reusable systems to last longer. Lightweight structural components are improved for longevity and resistance to cyclic failure. Overall, required system redundancies are minimized and a soft-abort capability is integrated to allow a return to launch site (RTLS) capability. Each of these advances contributes to MTV responsiveness.

Reusability is essential for routine operations, but some expendable systems still launch in 2025. A small portion of heavy lift is accomplished by the evolved expendable launch vehicle (EELV), but emerging third generation propulsion holds promise for NASA and commercial reusable heavy lift capability. The remaining heavy payloads are adapting to the standardized MTV requirements to avoid the excessive cost and environmental concerns associated with expendables. Eventually, all spacelift will be accomplished using reusable vehicles, but MTV performance increases are required to capture the entire spectrum of missions.

High I_{SP} Propulsion

To satisfy all MTV performance requirements in 2025, high I_{SP} propulsion is a primary solution characteristic. The 2025 commercial industries dominate the conventional solid and cryogenic rocket launch market. These corporations and nonstate actors have developed reliable launch schedules with safety records similar to that of the airline industry, standardized chemical propulsion systems, decreased payload volumes and weights, and streamlined infrastructure costs. Foreign governments, unconstrained by environmental considerations and zero-defect requirements, use 1990s space technology for attracting commercial enterprises to satisfy their own national objectives. Though these systems optimize expendable technology, they cannot compete with a high I_{SP}, reusable MTV.

In 1994 Lt Gen Jay W. Kelley, chairman of the *SPACECAST 2020* study, tasked the faculty of the Air Force Institute of Technology (AFIT) to investigate unconventional approaches to solving national spacelift problems.[6] One of the identified problems was the current limitations of I_{SP}. Conventional chemical propulsion is reaching its maximum I_{SP} of 450 seconds. This conventional chemical limit, analogous to the sound barrier, suffices in propelling payloads to LEO, but does not give the propulsion margin to enable true mission operability in space. Unconventional approaches are necessary to break through the chemical propulsion limits and meet the flexible operational requirements of 2025 spacelift.

Propulsion, coupled with structural mass fraction improvements, continue to drive technology in 2025. Presently, the cost of placing mass in orbit is $20,000 per kilogram (approximately $10,000 per pound), and this cost is proportional to the dry-vehicle weight of the lift vehicle to payload, the supporting structure, and the energy of the fuel.[7] *New World Vistas* also advised research into the "computational design of energetic materials," lighter satellite payloads, and lighter lift vehicular materials coupled with lower mass-to-fuel ratios and compact computer diagnostic/control systems, which support the 2025 spacelift solution characteristics.[8] Lower mass fraction and streamlined infrastructure are discussed later in this chapter.

High-I_{SP} technology advances enable the 2025 spacelift system to consist of versatile, vertical launch and combined vertical or horizontal landing recovery operations. The 2025 MTV employs a second "transitioning to third" generation propulsion system, which generates both high I_{SP} and high-thrust. High-efficiency ion drive systems

(solar and nuclear electric powered) are primary maneuvering systems on satellites and OTVs. These systems maximize I_{SP} without requiring the high-thrust needed to reach escape velocity in the ETO mission. The development of future unconventional fuels are a synergistic DOD, NASA, and commercial effort, which requires extensive sharing of information to spur the technology push required for reliable, high-energy, high-thrust propulsion.

Presently, the *Space Launch Modernization Plan* states that the current and projected funding is insufficient to support even a meaningful core space launch technology research program.[9] To create a core technology research base for furthering only current spacelift concepts (projected to 2013), which includes existing cryogenic and solid fueled upgraded launch vehicles, evolved expendable launch vehicles, and evolved reusable launch vehicles, the study recommended funding be increased from the current $45 million to $120 million.[10] The final plan lacks any revolutionary propulsion concepts and, therefore, does not provide the futuristic outlook needed for 2025. It recommends evolved expendable rocketry, increased cooperation with Russia for advanced engine technology and performance data, and pooling resources of the international community, rather than the strategic pursuit of unconventional propulsion alternatives. For achievement of routine spacelift operations, the US needs a strategic vision that drives propulsion technology towards unconventional solutions to achieve high I_{SP}. Revolutionary and evolutionary propulsion advances, which have the potential to achieve a third generation "on-demand" propulsion system, are required to provide the full spectrum of MTV capabilities.

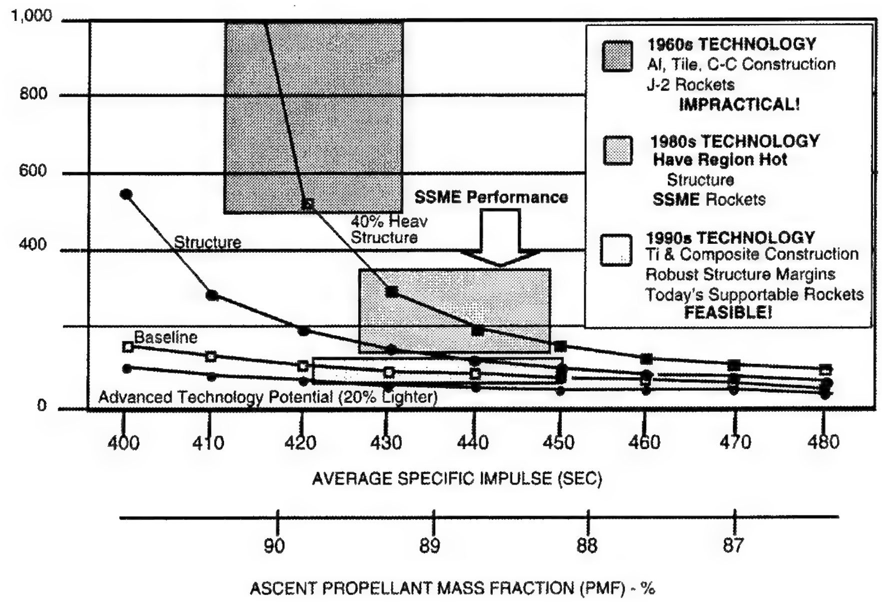
Modular Mission Packaging

Modular mission packaging is also not a new concept, but one derived from the X-33 concept of launching modularized payloads, which include satellite constellations, weapons deployment, logistics, and, even personnel.[11] Using encapsulated payloads with standard vehicle interfaces, mission flexibility, and responsiveness are enhanced, and ground operations are streamlined. The payloads are deployed from the payload bay singularly or in an integrated package. Moreover, the payload package is delivered and stored hours, days, or months in advance. The pilot of the vehicle can fly virtually from the ground, or fly in the manned mode if required for strike, surveillance, or mobility missions. The manned mission package has less residual capability, since the modular crew compartment uses some of the volume and performance normally dedicated to payload.

Economical Mass Fraction

Coupled with the decreased mass fraction due to propulsion technology 2025 spacelift takes advantage of continued advances in light weight composites. Figure 2-1, disregarding the space shuttle main engine (SSME) performance, demonstrates the improving relationship between the dry vehicle weight, mass fraction, and specific impulse as technology advances over time. The upper lines demonstrate that the heavier structure increases propulsion design risk (e.g., a 20 second I_{SP} shortfall can double the vehicle dry weight requirements). Conversely, given the baseline shown in the graph, one sees the immediate benefit of even 20 percent lighter future structural composites. Even a large change in engine performance does not significantly add to the dry weight of the vehicle.

The applications of lightweight composites to structural materials continue to be integrated into air-breathing systems as demonstrated by the B-2 and the MV-22 Tiltrotor aircraft projects.[12] These advances also reduce the size and weight of many payloads. Most satellite systems, deployed in distributed constellations, display trends toward weights in the 10s to 100s of pounds, driving most lift into the medium and light categories.



Source: Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, ***2025*** Support area, 6 March 1996. (Secret) Figure is unclassified.

Figure 2-1. Mass Fraction Reduction Baseline

The 2025 spacelift uses ultralight composite materials, which include structural composites, high/low temperature resistant materials, and revolutionary manufacturing technologies (singular crystal structures, automatic winding, and thermopultrusion).

Lightweight electronic systems employ fiber-optic technologies with adaptive commercial electronics (such as guidance) and self-diagnostics with expert systems, automated self-repair and reroute, computer programming advances (autocoding, molecular storage), and artificial intelligence.[13] Moreover, advances in high-temperature superconductors reduce friction requirements, produce more efficient power generation and engine systems, and reduce the component size of equipment. The above technologies help to reduce the MTV's dry weight, which, in turn, improves mass fraction.

This technology push utilizes and develops lightweight structural components with a long-design life and resistance to failure within reasonable engineering criteria. The combination of high I_{SP} propulsion and light dry vehicle weight results in economical mass fraction. MTV's low-mass fraction and high-energy propulsion give it the performance needed to satisfy all customers.

Streamlined Infrastructure

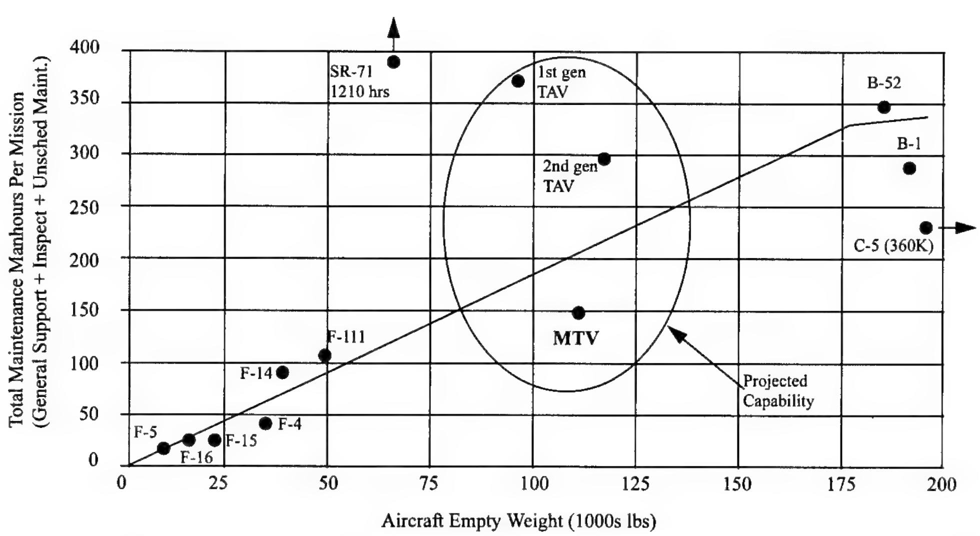
The 2025 spacelift infrastructure consists of small, modular general purpose facilities and a minimal processing/operating team. The 1995 NASA report of shuttle ground operational efficiencies noted that "the life cycle cost triangle of flight hardware, processing facilities/GSE, and headcount *must be dramatically and radically reduced*" to pursue an affordable operational tempo.[14] Additionally, the direct failure and opportunity costs experienced by the current space program must be eliminated.

The 2025 spacelift is a streamlined organization using the technician-level maintenance structure coupled with civilian technical advisors. The armies of technicians employed to launch rockets in the 1990s are no more. Figure 2-2 proposes

first generation MTV maintenance requirements. Using the above solution characteristics, the 2025 Spacelift system pushes spacelift maintenance requirements toward today's fighter maintenance levels. Reliability is ensured through standardized operation programs augmented by real time, continuous diagnostics and artificial intelligence (AI) driven self-repair and rerouting. Stand-downs due to failures are limited locally to specific MTV squadrons and do not necessarily ground the entire spacelift system. While investigations are conducted, operations are not normally impeded.

The 2025 spacelift system combines easy maintenance and engine access with interactive computer diagnostics and fault tracing. Ground operations use common equipment and modular component replacement with post-repair, two-level maintenance (2M) capability. Modular command and operations centers, coupled with vertical launch characteristics, enable a smaller physical infrastructure and basing requirements. Virtual pilot control operations lead to larger cargo payload deliveries without human life support concerns. Modular payloads generate generic loading operations and real-time mission flexibility. The composite nature of the missions reduces pilot specialization requirements. To mitigate the risk of an enemy targeting MTVs, the modular organizational concept provides mobility for flexible orbital access from numerous launch facilities.

Current launch operations in the 1990s are concentrated at Cape Canaveral Air Force Station, Florida, and Vandenberg Air Force Base (AFB), California. In 2025 physical spacelift infrastructure is more dispersed to include operations at higher altitude locations, closer to the equator for greater orbital access and more remote for increased public safety. Primary MTV locations include Peterson AFB, Colorado, and Holloman AFB, New Mexico. Clear launch pads, free of massive towers and other support facilities, provide simple ground operations and easy access maintenance. Encapsulated cargo reduces payload processing facility requirements. The resulting infrastructure is less expensive to maintain and facilitates routine operations.[15]



Source: Phillips Laboratory, *Advanced Spacelift Technology* (U), 1996. Provided current airframe maintenance data only. (Secret) Figure is unclassified.

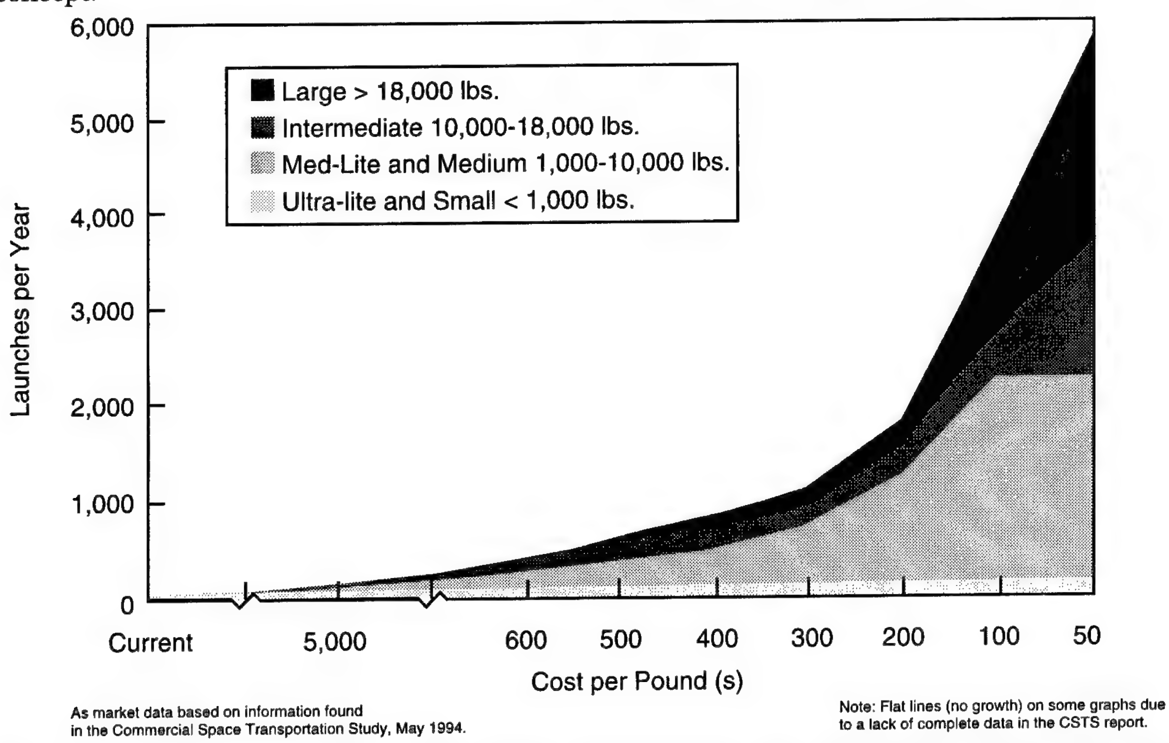
Figure 2-2. Reusable MTV Maintenance Requirements

Operational Simplicity

The 2025 spacelift system exploits advances in reusability, propulsion, and materials to meet spacelift, ISR, strategic strike, and mobility requirements with a single platform. Complex operational solutions to such reusable vehicle performance as a mothership, refuelable craft, or magnetic rail accelerated vehicle proved too costly. Each of these operational solutions work around to the propulsion challenge required extensive additional infrastructure and industrial base support. The Black Horse refuelable spacecraft concept was touted in the SPACECAST 2020 study.[16] With the added development, operations, and support costs of a mothership, an oxidizer transferring airframe, or a complex, inflexible rail launch site, these novel approaches to increasing performance could not compete with the low life-cycle cost of a SSTO MTV concept.

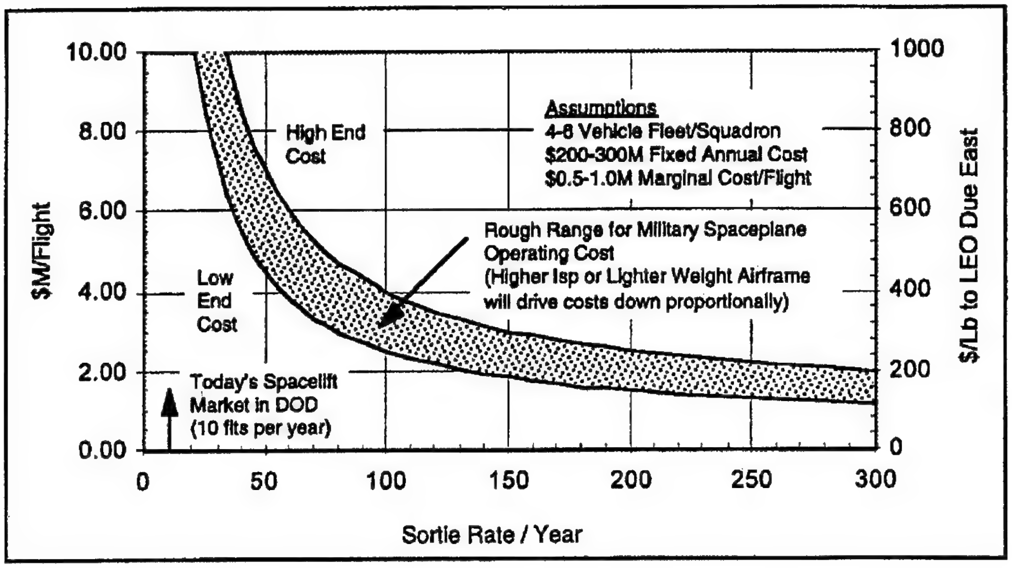
Affordability

By employing the combination of these solution characteristics in an operational environment, spacelift becomes affordable. Figure 2-3 demonstrates the commercial flight-rate potential as MTV launches become operational and cost per pound is driven toward \$200/lb. Further, history shows that the introduction of new operational transportation systems opens new markets, which, in 2025, include space exploration, space economic resource exploitation, hazardous waste disposal, rapid response commerce, and space settlement. For the military, the 2025 spacelift system results in rapid response supporting core competencies at an operationally affordable cost. The initial driver of cost reduction is reusability. Other drivers include decreased personnel overhead and improved reliability. The remaining solution characteristics described above contribute to further cost reductions.



Source: National Aeronautics and Space Administration, "Space Propulsion Plan" (draft), Marshall Space Flight Center, 22 January 1996, 8.

Figure 2-3. Commercial Launch Potential



Source: Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, ***2025*** Support area, 6 March 1996. (Secret) Figure is unclassified.

Figure 2-4. Impact of Flight Rate on per Flight Cost of an MTV

Life-cycle costs for an MTV wing is comparable to current bomb wing requirements adjusting for inflation, but the utility of the vehicle makes it more affordable than maintaining separate mission platforms. As figure 2-4 illustrates, the combination of the solution characteristics (assuming nominal operating costs) and operational sortie rate (150–200 sorties/year) has the real potential to achieve $200 per pound payload cost for a third generation MTV.

Notes

1. Air Force Strategy Division, *Air Force Executive Guidance*, Office of the Secretary of the Air Force (Washington, D. C.: Government Printing Office [GPO], 1995), 2.

2. Dr. Robert Zurbin, "A Question of Power," *Ad Astra*, November/December 1994, 40.

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4. Under Secretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy (Washington, D. C.: GPO, 1995), Executive Summary, 23–29.

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Chapter 3

National Spacelift System Capabilities

No one can predict with certainty what the ultimate meaning will be of the mastery of space. (It may) hold the key to our future on earth.

—President John F. Kennedy

Using the horizons mission methodology, the 2025 spacelift architecture is an emerging third generation system that has taken advantage of technology advances since the early 1990s. The systems characteristics and core competency missions are described in the 2025 environment, and notional progress is shown from first through second generation systems. Propulsion is described in detail in the appendix, because it is the pivotal technology push required for success of the system. The progress to 2025 occurs in three distinct steps: a first generation system exploiting current propulsion technologies, structural composite advances, and low-cost technology reusable demonstrators; a second generation system integrating evolutionary/ revolutionary advances in conventional chemical propulsion, technological advances in structures and computers, and refinement of the first generation operational system; and, finally, an emerging third generation system performing all required lift and mission requirements with refinements in second generation propulsion, compact fuel storage, and vehicle dry-weight reductions.

2025 System Characteristics

The 2025 spacelift system is derived through incremental application of technology and operational enhancements. This system description analyzes the progress toward 2025 based on the characteristics outlined in tables 1 and 2. Table 1 compares the attributes of a notional X-33 demonstrator and first through third generation MTVs against today's systems. Table 2 compares the attributes of notional first through third generation OTVs.

Primary Systems

The primary spacelift systems are divided into medium/light lift and heavy lift. The third generation MTV supplies 100 percent of all medium/light lift missions up to 30,000 pounds in the ETE and the ETO environments. The small market of heavy lift is accomplished by EELV, but the second generation commercial MTV and emerging third generation systems are rapidly consuming the market. As MTV proves its economic viability, more large payloads downsize. In the US, the advanced MTV spacelift wing strengthens air- and space-core competencies through a standardized modular command structure, modular and interchangeable payloads and weapons bays, technician-level maintenance, and on-demand responsiveness. In the STS environments, the OTV operates in conjunction with the international space station and/or the cislunar space defense station. Commercial OTVs perform satellite placement from LEO, satellite and station repair, research, and space debris removal. The DOD maintains a squadron of armed military OTVs for counterspace, force application, deterrence, and space-denial missions. Additionally, the military OTVs perform routine satellite maintenance, defense satellite positioning, and satellite repair on the national space architecture. They are attached to the space station defense directorate, which also performs the international space traffic control mission.

Table 1
MTV Systems Attributes

	Current Systems	X-33	1st Generation MTV	2d Generation MTV	3d Generation MTV
Cost/pound	$10,000	Developmental	$5,000-$8,000	$1,000	$200
I_{SP} (seconds)	450	450	450	450–800	>1,000
Reusable	No	Yes	Yes	Yes	Yes
Scale	not applicable	2/3 MTV	X-33 + 20%	Full	Full
Weight (lbs)	150,000–250,000	50,000–80,000	~100,000	95,000	90,000
Capability (lbs to LEO)	up to 50,000	Suborbital Mach 15 (can pop-up small payloads)	<10,000 (up to 28,000 with pop-up & reply	20,000 SSTO	up to 30,000 SSTO
Response Time	Months	Days (Demo Hrs)	Hrs to a Day	Hrs	Minutes

Table 2
OTV Systems Attributes

	1st Generation MTV	2d Generation MTV	3d Generation MTV
I_{SP}	High	High	High
Thrust	Low	Medium	High
Reusable	Yes	Yes	Yes
Weight (lbs)	30,000–40,000	30,000–40,000	<30,000
Response Time	weeks	hours	hours
Propulsion	Solar-ion	Nuclear-ion	Fusion or Antimatter
Primary User	Commercial	Military	All

Multipurpose Transatmospheric Vehicles

The 2025 emerging third generation MTV is a high I_{SP} (greater than 1,000 seconds), medium-lift vehicle that integrates composite materials, advanced computer diagnostics, fiber-optic and superconductor technology for compact energy generation systems. It also integrates a modularized infrastructure for maximum responsiveness and flexibility. The propulsion system is an "accelerator class" engine combining laser pulse detonation (LPD) and magnetohydrodynamics (MHD) fan-jet principles, as outlined in the appendix. The emerging fusion and antimatter technologies hold promise for a strategic application of the MTV with unlimited range enabling Space Command (CINCSPACE) to finally possess a planetary area of responsibility (AOR). The following data describes the vehicle design advances required through first generation and second generation vehicles.

First Generation MTVs

The X-33 program generated the first reusable demonstrator, which proved the potential for routine operations. The first generation follow-on military MTV is 20 percent larger than the X-33 demonstrator. The MTV space system retains 20 percent propulsion capability margin to enhance operational reliability. The MTV, a vertically launched, single stage ETO and ETE system, capitalizes on current technologies. The vehicle uses cryogenic fuels in the X-33-developed integrated powerhead rocket engine (see appendix) to achieve orbit. For lift missions greater than 10,000 pounds, the MTV uses the X-33 demonstrated satellite "pop-up" and refly capabilities. In the pop-up mode, the payload is deployed in the upper atmosphere and uses an expendable upperstage to place it in LEO. For the refly mode, MTV deploys small reusable aerodynamic platforms for both ETE and ETO missions. These small winged vehicles are capable of making drastic orbital plane changes in the upper atmosphere by using aerodynamic forces on their wing surfaces. The MTV performs space superiority missions through tailored, standardized, modular mission payloads and satellite refly. Additionally, in the transatmospheric ETE mode, the MTV demonstrates force application and a rapid response ISR capability.

Structural Materials

The current advances in composite technologies and thermal protection systems (TPS) are incorporated into a structure that is 20 percent larger than the X-33 but only 10 percent heavier, which should allow significant operational cost reductions. The TPS uses advances in current carbon-carbon (C-C) and carbon-silicon (C-Si) systems and thermoplastic pultrusion technologies derived from enhanced computer modeling of structural fluid dynamic solutions.[1] These thermoplastic pultrusion manufacturing techniques produce tougher mechanical properties with longer life cycles. Additionally, the process requires no chemical curing, so production rates increase to lower lengthy production costs. Cryogenic fuel storage builds on current aluminum-lithium (Al-Li) technologies. Electrical components and computers take advantage of advances in high-temperature superconductors and first generation artificial intelligence (AI), and the vehicle uses fiber-optics for all control systems. Superconductors are manufactured to operate at 250 degrees Kelvin (-23 degrees Celsius), which currently seem viable by 2002.[2] This enables order of magnitude smaller control and pump motors using current refrigeration systems allowing either more payload or fuel to be carried. Third order of magnitude increases in computing power and advances in AI enabled the vehicle to incorporate a real-time, self-diagnostic system with automatic self-repair and reroute capability.[3] The system contains an interactive interface for technician fault isolation, rapid identification, and component

replacement and enables a much smaller operational launch team.

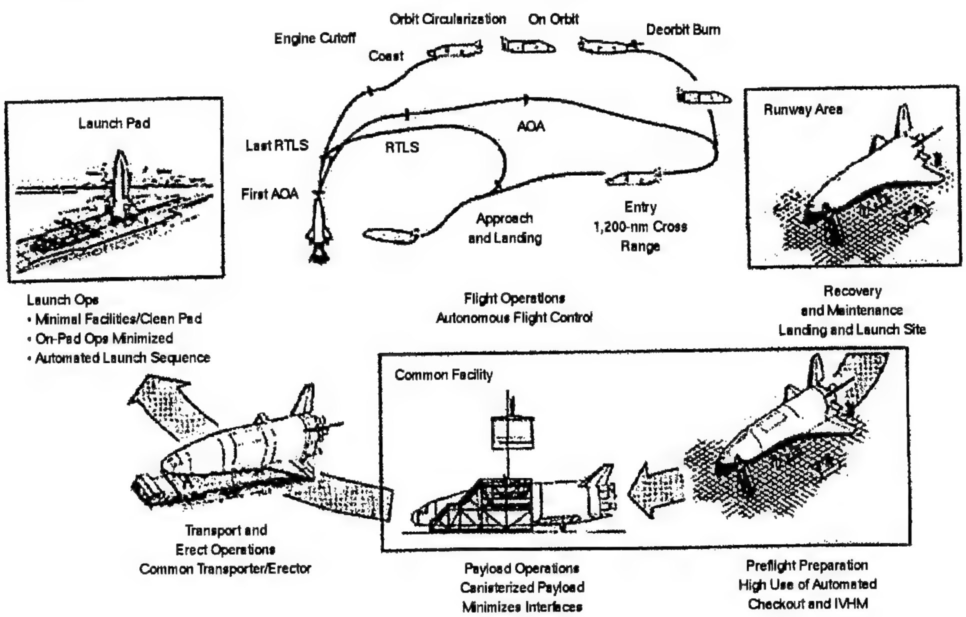
Modular System Packaging

The MTV can be a manned or unmanned vehicle, depending on the mission. The vehicle in the manned mode uses a two-person crew: a pilot and a mission specialist, which can be a counterspace specialist, weapons officer, logistics specialist, or a satellite-deployment specialist. The integration of fiber optics, superconductors, and advances in space life support science produces a smaller modular crew life support system, which is removed to increase payload size in the unmanned mode. Virtual piloting is conducted from a modular command center and is accomplished by way of integrated satellite link using current computer technology advances and the improved global navigation capability. Payloads are encapsulated for both ETO missions and ETE. Modular payload and weapons deployment is successfully tested by the X-33 demonstrator.[4] Human life support for special operations forces (SOF) deployable modules are in the test phase for the second generation vehicle.

Operational Infrastructure

The US Spacelift Wing uses an organization analogous to the 1995 Air Force wing structure plus a commercial technical assistance division. The military MTV takes advantage of commercially driven material technologies with investments in propulsion advances to deploy space-based weapons, lasers, counterspace technologies, and logistics. The spacelift wing is located in two main operating aerospace bases, but the command structure is modularized for rapid deployment to any US Air Force base. Figure 3-1 shows a conceptualized operational turn around for a potential MTV-type design. Relying heavily on vehicle self-contained diagnostics, a common facility is used for automated preflight and payload operations.[5]

Preventive maintenance and preflight are standardized procedures for technicians employing a "blue-suit" concept. The civilian



Source: Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, ***2025*** Support area, 6 March 1996. (Secret) Figure is unclassified.

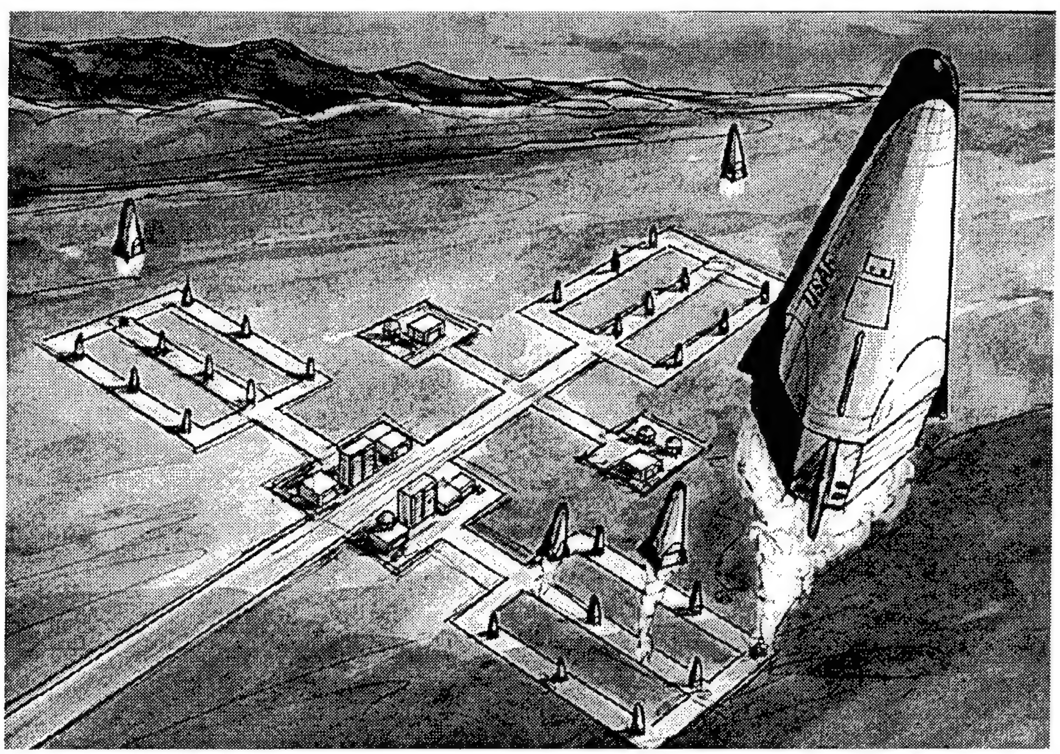
Figure 3-1. Conceptualized Operations for the MTV

technical assistance group handles major technical problems. Components are line replacement units (LRU) with separate two-level maintenance system outside of the preflight facility. Average turnaround time is less than six hours, including refueling, but a priority aerospace mission sortie turn around of less than three hours is possible. Prior to launch approval, on-pad alert MTVs perform a 15 minute diagnostic check, yielding a global response time of less than one hour.

The base additionally contains hydrogen/oxygen generation and storage facilities. The command structure consists of a communications building, which performs administration and is tele-linked to the space traffic control center in the space station's defense directorate, and the virtual command center, which holds the pilot control system and mission briefing areas (secure video-teleconference capable). Figure 3-2 is a conceptualized picture of an operating spacelift wing employing one possible vehicle configuration.

Second Generation MTVs

The second generation MTV integrates revolutionary propulsion into an improved first generation MTV aerospace frame. Dry-vehicle weight is reduced another 5 percent. The propulsion system is a first generation laser pulse detonation and magnetohydrodynamic "accelerator class" engine with laser air spike technology (see appendix). This propulsion system is designed to operate each engine variant in its most efficient mach regime. To increase engine thrust efficiency in the laser detonation cycle, the cyrogenic propulsion system uses a boron additive.[6] The increase in I_{SP} to greater than 600 seconds has



Source: Dr Dick Mueller, Washington Strategic Analysis Team, "Global Response Aerospace Sortie," briefing, 6 March 1996.

Figure 3-2. Artist's Rendering of First Generation Spacelift Wing

rendered the satellite pop-up maneuver obsolete, since most payloads can be directly inserted into orbit. Propulsion margin of 20 percent is easily maintained. A commercial heavy lift MTV demonstrator is being tested, and a commercial passenger MTV is on the drawing board. The second generation MTV is the joint bomber/logistics transport capable of contributing to air- and space-core competencies. Advances in artificial intelligence and superconductors are incorporated into a fully self-contained preflight and diagnostic system with real-time self-repair and reroute. Additionally, these advances have reduced required personnel for refueling and maintenance support.

Structural Advances

Thermoplastic protrusion technologies are commercially adopted, and thermosets are past history. Research at Sandia National Laboratories has developed powder metallurgy with high-gas atomization, which is now in production.[7] The MTV is an all-composite design with Al-Li cryogenic storage tanks. Composites continue advances in C-C and C-Si with titanium-derived alloys to lower structure weights 20 percent below baseline.[8] These manufacturing technologies are commercially derived and provide an economical space frame with 20 percent lighter materials, long life cycle, and high strength, to further reduce life cycle costs. Additionally, the structure is supported by a commercial as opposed to military industrial base. This arrangement should spread spare and replacement costs across a larger group. It also should provide larger basing opportunities. To reduce control system weight, the system employs buckytubes (molecular-level electrical materials with AI) which are the electrical information carriers for the self-diagnostic system.[9] They also manipulate micromechanical devices in the MTV's control systems.[10] The MTV's surface is monitored by first generation shape memory alloys, which use piezoelectric actuators and fiber-optic sensors to transmit MTV control surface information to the real-time diagnostics that allowed personnel reductions.[11] Superconducting quantum interference devices (SQUIDS) detect and measure the earth's magnetic field and are integrated into the MHD (an engine which uses the earth's magnetic field to generate energy) control portion of the "accelerator class" engine.[12] A zero-degree Celsius superconductor has revolutionized the pump and motor industry, leading to a four-fold reduction in weight and size and again improving payload or fuel capability. These realistic electrical advances reduce heat dissipation requirements, lower both structural and volumetric weight requirements, and enable the development of real-time diagnostics and control systems, which improve reliability and operability.

Modular Payloads

The improvements in propulsion negate the pop-up requirement for satellite movement to LEO, but modular payloads remain important. The SOF deployment system is tested successfully and scheduled for production. Space special operations forces are being trained for future transatmospheric insertion. The MTV has assumed all strategic bombing missions.

Infrastructure

Continued advances in materials, computing, and propulsion, lengthen mean time between overhauls. Commercial advances continue to be exploited by the military, and the volume of spacelift guarantees a robust industrial base. The self-diagnostic capability has reduced technician support. Pilot specialization is not required, because the same crew performs all missions. Turnaround time is less than three hours, with a potential to drop to 90 minutes for a priority sortie. Real-time diagnostics enable five minute alert status on the pad. Deployment of the US Spacelift Wing to anywhere in the US is less than 24 hours for a limited time depending on mission and orbital access required.

Orbital Transfer Vehicles

The emerging third generation military OTV is powered by a revolutionary engine supplemented by emergency high-density hydrogen fuel cells. While this system is in the demonstration mode, OTV requirements are met with first and second generation OTVs. The OTV squadron is supported by the international space station defense directorate, which incorporates the space traffic control system, or is part of either a cislunar or an orbital space defense station. The OTV carries out the routine operational missions of satellite deployment, repair, refueling, rearming, and reconnaissance. Further, the OTV is armed for counterspace, space denial, and space-force application missions. The advantages of this system are economical space architecture maintenance, rapid response positioning of assets, and global reach missions for space superiority. The vehicle is a single piloted vehicle (F-16 sized), unmanned and controlled virtually in the defense directorate control center. Structure advances and diagnostic computer advances are identical to the MTV systems. The following are the advances required from first through second generation vehicles.

First Generation OTV

The OTV system capitalizes on the satellite capture demonstrations from the shuttle program. Research into magnetic satellite capture is on-going. The OTV is considered an integral part of the IPDS. The propulsion system is solar-electric ion drive; the low thrust is supplemented by emergency fuel cells during national contingencies. For ion drive, solar energy is used to ionize an inert gas and extract it through a nozzle to produce thrust (see appendix). The infrastructure is attached to the defense directorate and, in national emergencies, is operationally chopped to the US Spacelift Wing. The OTV demonstrates the first space laser satellite destruction. Composite technologies and unknown orbital trajectories make the vehicle stealthy. Maintenance of the OTVs is accomplished by modular repair coupled with MTV similar built-in diagnostics, automatic preflight, and technician-level maintenance. The first generation OTVs are attached to the international space station infrastructure or capitalize on a dedicated cislunar or orbital defense space station, and financial investment recapitalization occurs within seven years (similar to emerging industries). Overhauls of the OTVs are conducted on earth every two years.

Second Generation OTV

Nuclear-electric ion drive propulsion is incorporated with higher thrust. The nuclear energy generates a higher degree of ionization generating more thrust and range. These attributes enable the military OTV to meet the mission flexibility and responsiveness requirements. Satellite capture using magnetic fields is a demonstrated capability. The spacelift infrastructure has expanded to include OTV overhaul in space. Structure composites and computer advances are identical to MTV development. Communication advances enable OTVs to be permanently part of the US Spacelift Wing with the defense directorate as the on-scene headquarters. The MTV missions and the OTV missions enable space superiority and global force application. Fusion and antimatter propulsion technologies hold promise for the third generation OTV in a strategic role. CINCSPACE finally possesses a planetary AOR defined by the Earth-Moon system, which is a sphere inscribed by the moon's orbit.

Countermeasures

The stealth characteristics of the MTV are its high speed (>Mach 25), large portion of composite structure, and unpredictable orbital position. Counterspace devices on satellites, ground-based laser devices, and direct attack on launch facilities are the

greatest threats. The long range of weapons deployment and rapid sortie ability cause unpredictability and standoff capability. Rapid deployment of the launch infrastructure prevents effective strategic targeting. The OTV is stealthy by nature, but it is susceptible to international sabotage at the space station and counterspace satellite defense weapons. The OTV's orbital unpredictability and speed are its greatest assets. Internal defense on the station is a requirement. More powerful lasers, kinetic weapons, and particle beams give extended standoff for force application roles. The OTV also is capable of nonlethal satellite blinding and deception.

The MTV/OTV system performs two basic space deployment tasks: lifting payloads to orbit and transferring payloads between orbits. The utility of systems performing these functions is measured in terms of weight to orbit, volume to orbit, civilian surge capability, system responsiveness, and reusability for MTVs. OTV utility is measured in terms of timeliness and reusability. In addition to the spacelift tasks, the MTV is used for airlift, strike, and ISR tasks. The MTV reaches anywhere on the globe in less than an hour, so it can perform vital missions rapidly. For example, airlift systems are employed to move a brigade of troops to a theater, but MTV can provide rapid SOF insertion for squad-sized units. These Air Force Institute of Technology-derived utility measures are used to determine which weapons systems in the ***2025*** study hold the most promise. The following is a more detailed qualitative comparison using required system attributes.

The MTV/OTV system was selected from a variety of systems that addressed the spacelift mission (table 3). Each of these systems provided enough capability to meet the bulk of mission requirements, but the EELV was chosen initially by other studies, because it was the only system with low-development risk and because it captured the entire current mission model. While EELV provided a needed initial cost reduction, it was the only

Table 3
Qualitative System Comparison

System Attribute	Refuelable Blackhorse	Single Stage MTV	2-Stage with Mothership	Magnetic Rail launched TAV	EELV
Capability (lbs to orbit)	Good-Excellent	Good-Excellent	Good-Excellent	Good-Excellent	Excellent
Reusable	Yes	Yes	Yes	Yes	No
Responsiveness	Good	Excellent	Good	Good	Fair
Flexibility	Good	Excellent	Good	Fair	Fair
Soft abort	Good	Good	Good	Good	None
Logistics	Good	Excellent	Good	Good	Fair
Operational Simplicity	Good	Excellent	Good	Good	Fair
Cost ($/lb to LEO)	Good	Excellent	Good	Good	Fair
Development Risk	High	Medium	Medium	Medium-High	Low

expendable system; so, it did not offer the promise of routine operations. A reusable system was destined to take center stage. Two stage systems and the single stage MTV had medium risk while the magnetic rail and oxidizer refueling systems presented some unique new technical challenges. A magnetic rail similar to the EELV was tied to extensive infrastructure, which reduced its flexibility as a multipurpose system. The major discriminator between MTV, blackhorse, and two stage to orbit vehicle was operational simplicity. The Blackhorse concept required added development and maintenance of a tanker capable of refueling oxidizer at high speed in addition to the basic vehicle. This additional infrastructure increased logistics requirements, reduced flexibility of deploying the system, and complicated responsiveness. Similar concerns existed with the mothership in the two stage to orbit concept. This state left the MTV as the best choice to provide simple routine operations capable of satisfying all existing and potential customers.

The first generation MTV system acquisition cost was $1.7 billion, and the prototype vehicles were scheduled for fielding in 2003. The first functional vehicle was declared operational for 2010. With routine operations already proven, second generation costs were held to under $1 billion, and the system was declared operational in 2020. Third generation systems are still in development.

Notes

1. Basil Hassan et al., "Thermophysics," *Aerospace America*, December 1995, 19.
2. Paul C. W. Chu, "High Temperature Superconductors," *Scientific American*, September 1995, 128–31.
3. Douglas B. Lenat, "Artificial Intelligence," *Scientific American*, September 1995, 62–64. Lenat describes current ability for computer systems to reason and projects near future abilities to incorporate into commercial applications.
4. Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, ***2025*** Support area, 6 March 1996. (SECRET). Information extracted is unclassified.
5. Ibid.
6. Bryan Palaszewski, "Propellants and Combustion," *Aerospace America*, December 1995, 46.
7. Hassan, 19.
8. Sponable.
9. George M. Whitesides, "Self-Assembling Materials," *Scientific American*, September 1995, 116.
10. Kaigham J. Gabriel, "Engineering Microscopic Machines," *Scientific American*, September 1995, 120.
11. Craig A. Rogers, "Intelligent Materials," *Scientific American*, September 1995, 123–24.
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Chapter 4

Concept of Operations

Our destiny in space has always been inextricably linked to our launch vehicles.

—Astronaut Buzz Aldrin

Spacelift operations in 2025 will be primarily commercial. The market began transforming from one of reliance on national space programs and international consortiums to one driven by private industry in the 1990s.[1] As commercial markets continued to expand, the cost of launch decreased, as more and more commercial innovations capitalized on inexpensive access to space. Many commercial spacelift providers specialize in operations leaving manufacturing to someone else, much the way airlines have run commercial air operations for decades. Large corporations capable of building, launching, and operating space-based systems sell such services as communications and imagery instead of selling hardware and launches. A spacelift reserve fleet (SRF) of commercial MTVs, analogous to the commercial reserve aircraft fleet handles wartime spacelift surge requirements.

The DOD operates a wing of dedicated MTV vehicles to ensure spacelift responsiveness, global presence (ISR), and global power (strategic attack). These vehicles give commanders a flexible spacelift option and facilitate other ETO missions, like ISR, a small unit or troops, and/or equipment deployment, rapidly to a remote part of the world. The MTVs fly from a main operating base, such as Peterson AFB, Colorado, and Holloman AFB, New Mexico, but are capable of operating from many sites.[2] Operating bases are selected according to public safety, elevation, and proximity to the equator, but the system is capable of operating at any airfield to maximize flexibility.

The operating base consists of minimal facilities. A central operations center houses the virtual cockpits employed to fly the preponderance of unmanned missions. Fuel storage, maintenance, and a cargo-ready area are also sited with the vehicles. The crew for a mission consists of a pilot and a mission specialist, plus a ground-based crew chief and technician support.

The system requires minimum support in terms of a maintenance crew. It is capable of flying 100 missions without a major overhaul. The routine turnaround time is measured in minutes instead of days and is performed by technicians instead of engineers. Tech data is developed using AI and approved prior to operations to facilitate this capability. The MTV's expendable rocket predecessors were operated in accordance with a set of procedures developed or revised before each mission by an army of engineers. This R&D mentality led to many of the inefficiencies of spacelift in the last century. Built-in-test and fault tolerance streamline both operations and maintenance. Extensive use of the AI tech data and LRUs all but eliminates the need for a depot. The manufacturer serves in what little depot role is left.

The 2025 MTV incorporates standard interfaces for its modular payload packages. Though primarily an unmanned system, the MTV packages can contain crew compartments, satellites, weapons bays, or refly modules. MTVs are used in both the ETO and the ETE mission areas. The same crews are capable of space support missions, force enhancement and force application. The standard interfaces provide a baseline for the development of tech data

and facilitate the mission rates required to realize economies of scale. The large number of missions using the same multipurpose vehicle reduces the cost per pound to orbit by allowing development costs to be amortized over a greater number of flights.

While most satellites have evolved into smaller networks of distributed satellites, some heavy-lift requirements remain. Space station resupply and some reconnaissance satellites still need heavy lift, since some of them could not be shrunk while maintaining the quality of products.[3] Given the long-development timelines, the big satellites have not yet capitalized on the small reconnaissance technology now available. As a result, operational EELV heavy lifters still operate out of Vandenberg AFB and Cape Canaveral.

In the STS area, OTVs have commercial, civil, national, and defense missions as well. Operating like harbor tugs, commercial OTVs fall under the same SRF arrangement as MTVs with the military owning several dedicated units. OTVs dock at the international space station or the DOD defense station as a base of operations. From there, they push new satellites into higher energy orbits and retrieve satellites needing fuel, maintenance, or retrofit. Replenished satellites are then returned to their operational orbits. While the civil/commercial OTV is powered by solar-electric propulsion, the military version uses a nuclear-ion drive to give it a more rapid response time. The following is a notional scenario employing the operational aspects of the US spacelift system for illustration purposes.

A Plausible 2025 Scenario

The high-demand 2025 space lift system is incorporated into second generation fleets of MTVs transitioning to third generation. With a spacelift wing consisting of more than 40 operational MTVs and a squadron consisting of 10 OTVs, all US aerospace missions are obtainable. The US Spacelift Wing is the deterrent force with rapid response to anywhere in the world in less than an hour.

EELVs are being phased out in favor of the NASA/commercial cooperative heavy-lift MTV incorporating the "accelerator class" engine. The medium lift MTV operates with excess performance margin with a reliability record greater than 0.99.

Mission 45. The 45th mission of MTV #3 is scheduled for launch. This mission is preceded by systems check in the preflight facility, which checks structural integrity and interfaces with the vehicle's self diagnostics. A satisfactory check at the 45 sortie point historically indicates that 100 launch criteria will be met prior to overhaul. Finally, the modular payload is inserted into the cargo bay. The vehicle is delivered to the erection and launch area and refueled. Time elapsed is two hours. Previously, MTV #3 has boosted two medium-lift payloads to LEO for repositioning by the standby OTV to GEO in the last 36 hours. The unmanned, virtually piloted, MTV #3 has enabled the accommodation of increased payload.

MTV #6 is sending a human payload of six space technicians to the space station for the first phase expansion to an OTV overhaul facility. MTVs #7 and #8 have recently positioned modular components for the space station in LEO.

In the past 60 days, 39 missions have been flown including a record 11 launches in two days by three MTVs. Spacelift wing projects a four mission per day average by 2026. The MTV success has generated funding for 22 third generation MTVs and two, third generation propulsion demonstrators using a Penning Trap in a microfusion/antimatter propulsion system. Estimated cost per pound to orbit is $200/lb with projections to $100/lb in the next 10 years.

Perhaps the most remarkable aspect of the MTV/OTV system is that, with a wing of 100 vehicles and two squadrons of OTVs, if just 30 percent of the wing is mobilized at a sortie rate of two launches per MTV per day, a four-day launch schedule would yield 10.8 million pounds of lift for $4.3 billion. This is equivalent to the entire US spacelift in the 20th Century. During one year, it is possible to sortie each vehicle 70 times, including maintenance periods. A wing of 100 MTVs would put 315 million pounds into orbit at a cost of $126 billion. The weight is equivalent to putting three aircraft carriers in space! If the space shuttle were used, it would take 20 times as long at a cost of $4 trillion.

With the miniaturization of PGM weapons and reusable carrying capacity, space control enthusiasts once again claim that space superiority can by itself win wars and that space is the truly joint environment. The costs of conducting a seven day hyperwar with MTVs and OTVs would run about $10 billion excluding payload weapon costs. Decisive force is brought to bear within 40 minutes of the NCA decision. OTVs conduct routine refueling of the satellite constellation and rearming of the ABM defenses. A combined joint exercise in counterspace force application against a fictitious enemy's satellite system is forthcoming.

Notes

1. Marco Antonio Caceres, "Space Market Shifts to Private Sector," *Aviation Week*, 8 January 1996, 111.

2. Lt Col Jess Sponable, *Advanced Spacelift Technology* (U), Phillips Laboratory, PL/VT-X, briefing, Air University Library, ***2025*** Support area, 6 March 1996. (SECRET). Information extracted is unclassified.

3. Joseph C. Anselmo, "Shrinking Satellites," *Aviation Week*, 26 February 1996, 64.

Chapter 5

Recommendations

A hundred years from now people will look back and wonder how we ever managed our affairs on this planet without the tools provided by the space program . . . a world without spacecraft is as hard to imagine [as] a world without telephones and airplanes.

—Wernher von Braun

Spacelift's center of gravity is *ROUTINE OPERATIONS.* A paradigm shift in strategic thinking from the specialized R&D space focus to mission accomplishment in national security and national economic growth must be accomplished. The following passages summarize the requirements to develop an operational system based on incremental long-range technological and operational art advances.

As US spacelift transitions into an environment dominated by commercial providers, it is unlikely that the DOD will continue to support its own separate industrial base. At the October 1995 Air Force Association convention in Los Angeles, Secretary Sheila Widnall stated, "It is clear this nation can only afford a defense industrial base in those areas where there is no commercial activity."[1]

A key aspect to reducing the cost of spacelift is enlisting industry support in the commercial sector for the development of new systems. NASA administrator Dan Goldin is attempting to build such a partnership with the private sector to develop reusable launch vehicles. After experiencing an order of magnitude reduction in satellite cost per bandwidth over the last decade, NASA is teaming with industry to realize a $10,000 per pound to $1,000 per pound reduction in the cost of launch.[2] Looking a generation beyond the $1,000 per-pound barrier, the $200 per-pound mark further enables commercial uses of space into such areas as entertainment and space tourism.[3]

Given the magnitude of spacelift challenge, no magic solution can resolve all of the issues instantaneously. Instead, the problem must be attacked incrementally. The first step is to address the crippling cost issue. The *Space Launch Modernization Plan* outlines how the country will change one of the current expendable launch vehicles into a family of vehicles capable of satisfying the myriad of lift requirements facing the country, from medium payloads to heavy payloads. The resulting EELV system requires sustainment of one system infrastructure versus the three systems currently maintained for Titan, Atlas, and Delta. But this "right-sized" infrastructure, combined with more reasonable processing timelines, is only the first step in controlling the cost of launch. Concurrent with the DOD expendable effort, NASA is pursuing a truly reusable spacelift system, the X-33. Capitalizing on the advances of the X-33, the first generation, reusable MTV must provide responsive operations with airline-style operations.

This first generation space MTV's primary focus will be routine operations with an expanding mission base. It will provide aircraft-like operations, improved reliability, technician-level maintenance, and simplified infrastructure. The system will remain cryogenically powered and will demonstrate operable spacelift operations without requiring revolutionary technology.

The next step will expand on the lessons learned with the initial MTV by pushing propulsion and material technologies

toward leading edge evolutionary technologies, including combined-cycle engines using laser pulse detonation, magnetohydrodynamics, and higher energy propellants. Combined with advances in reduced vehicle dry weight due to advances in materials and lighter weight fiber-optic avionics, the second generation MTV will see large improvements in performance. Finally, the third generation MTV will incorporate a high-energy propulsion system capable of producing an I_{SP} of greater than 900 seconds. Combined with further structural advances in materials, which decrease the dry weight of the vehicles, and increased sortie rates, this resulting generation of MTVs will possess a lower mass fraction and will provide an order magnitude improvement in cost per pound to orbit.

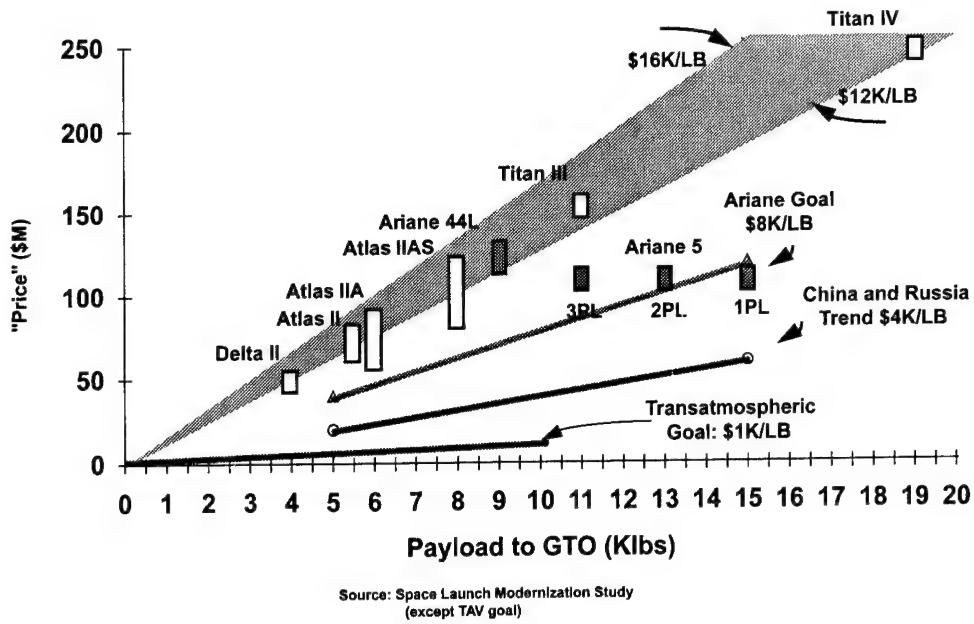
The key to realizing these leaps in spacelift performance is to protect the seed money for a variety of technologies while the initial steps take place. Propulsion and material technologies drive the development of MTV systems. Early reductions in the cost of launch from EELV and first generation MTVs are gained by directing investment in these key technologies. The DOD must form partnerships with NASA and the commercial sector to provide synergy in achieving this goal. Stovepipe efforts create stovepipe systems which can no longer be afforded. National Space Strategy must be examined and revised every couple of years to ensure the efforts of all sectors are properly orchestrated with the DOD as lead agent to ensure that it is in concert with the National Security Strategy.

Once the ETO problem is mitigated, the funds required to assure access to space can begin to address the problems of assured access through space (ETE) and assured access in space (STS). These ETE frontier spacelift missions enable spacelift as a true force enhancer. The ETE mission is a natural outgrowth of an affordable and efficient, high-energy MTV. Once the system becomes plausible, the military is just one of many customers in line to take advantage of the leap in capability. The military MTV must be developed as the future strategic war fighting vehicle.

STS missions will benefit from some of the same technological advances that facilitated the high-energy reusable vehicle. High-efficiency, low-thrust solar ion propulsion systems will provide inexpensive orbital transfer for those customers able to wait weeks for their satellite to reach programmed orbit. Military customers requiring a quicker route to orbit will use a nuclear ion propulsion system on a similar vehicle bus. To best utilize the expanded spacelift mission area of 2025, the DOD will need to refine the concepts and define the entire spectrum of missions now!

The overriding factor to the spacelift problem is routine operations, which ultimately leads to affordability. Combining solution characteristics described in this paper, affordability become the outgrowth of increased sortie capability and reusability. Given the increasing pressures of lower cost foreign goods (fig. 5-1), the motivation to lower costs is common to all sectors of the US space launch community. Commercial providers cannot regain market share at $10,000 per pound while facing a European trend of $8,000 per pound and Russian and Chinese trends towards $4,000 per pound. While a $1,000 per pound MTV does not capture all of today's market, it does provide the motivation to lower the weight of any cargo to the point where such reduction is physically possible.

Implementing the incremental approach outlined above provides a safe, realistic path from space launch to spacelift operations. It lowers the cost of the current system while providing a spacelift capability to meet the national defense requirements at any time during the incremental development. The ETO mission remains the cornerstone of spacelift operations. Once cost improvements are realized in the ETO area, expansion into ETE and STS missions becomes a reality.



Source: Undersecretary of Defense for Acquisition and Technology, *Space Launch Modernization Plan*, Office of Science and Technology Policy, 1995.

Figure 5-1. Launch Costs

To reach this 2025 spacelift vision, the initial effort must begin now. First, true reusability must be demonstrated in a first generation MTV. While NASA has the lead in the reusability track, DOD must stay engaged by supporting technology, ensuring the system meets military as well as civil/commercial requirements, and developing operational mission uses for the initial system, including pop-up and refly satellite options. Second, investment in propulsion technology must be pursued aggressively. The total DOD launch technology investment has atrophied at about $45 million per year.[4] A portion of investment dollars must be used to pursue such revolutionary propulsion systems as laser pulse detonation, magnetohydrodynamics, the "accelerator class" propulsion concept, high density fuels, and ion propulsion.[5] This propulsion development must take advantage of commercially derived advances in composite technology and manufacture (including thermopultrusion), metallurgy, and computers. The propulsion system must be able to power the MTV through all conceived mission profiles. Finally, development of innovative missions for a future MTV/OTV system must be studied relative to air- and space-core competencies. To become a viable foundation for global presence, planning for information dominance, precision employment, and space superiority *must begin now!*

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Appendix

Propulsion Advances
A Pivotal Technology

In 2025 spacelift second generation propulsion employment advances toward third generation propulsion systems. The MTV is a combination of revolutionary and evolutionary technology. The vehicle incorporates a vertically launched, single stage-to-orbit, "accelerator class" propulsion system. This propulsion system produces greater than 300 times the thrust (at less than Mach 6) of current systems with a specific impulse I_{SP} greater than 800 seconds. The fuel storage is dense, contained, or compact and contributes to lowering mass fraction. This propulsion system is derived from the evolutionary second generation, reusable launch vehicle, which incorporates evolved combined rocket/air breathing engine cycles employing an accelerator class laser pulse detonation and magnetohydro-dynamic propulsion system for atmospheric transport to orbit. Each engine cycle is optimized for a specific portion of the ascent profile. The second generation vehicle is derived from current propulsion systems based on the first generation military and commercial/NASA version of the space plane. The following are the notional advances required from first through second generation propulsion systems.

First Generation Propulsion Alternatives

Technical Considerations

Physics dominates spacelift, and Newton's Third Law, stacked heads true time which purports that for every action there is an equal and opposite reaction, holds true. To achieve orbital velocity, sufficient momentum (mass x velocity) must be generated to counteract the earth's gravitational pull. Launch vehicles expel expended fuel mass with velocity to propel itself through the atmosphere in the opposite vector. Translated, the thrust (the rate of change of momentum) required for propulsion is the mass flow rate times the velocity of the fuel. The primary measure of thrust-producing efficiency is the I_{SP}, which is measured in seconds as the impulse provided per unit weight of fuel expended.

X-33 Demonstrated Performance

Using the lower mass fraction available due to composite development and the additional payload capability made possible by the pop-up maneuver and refly options, the use of current cryogenic propulsion systems of low I_{SP} (less than 400 seconds) continue to execute heavier medium-lift missions from the upper atmosphere.[1] Employing an X-33-developed integrated powerhead rocket engine, a cryogenic propulsion system provides 250,000 pounds of thrust, yielding a 28-second improvement in I_{SP} and a thrust-to-weight ratio greater than 75:1.[2] The X-33 primarily provides the proof of concept for reusability and operational tempo. Further advances in cryogenic fuels are spurred through international pooling of information, including Russian engine and fuel pump technologies. The second generation systems take advantage of evolutionary advances in propulsion technology.

Other Current Propulsion Options

The Blackhorse (as outlined in *SPACECAST 2020*) propulsion technology spin-off is hydrogen peroxide propulsion with the combined monopropellant storage. Low I_{SP}

of hydrogen peroxide inhibits extensive development of this fuel source for a rapid response ground-to-orbit vehicle. Lockheed Martin reusable launch vehicle research is working toward to a linear airspike engine, which would improve I_{SP} through atmospheric flight using cryogenic propulsion.[3]

Second Generation Propulsion Options

Laser Pulse Detonation and Magnetohydrodynamic Fan-Jet

Pulse detonation is laser induced, high frequency, sequenced detonations of fuel in a closed tube with a nozzle on one end in lieu of conventional combustion. High efficiency, greater thrust is produced through the use of rapid energy release of detonation as compared to controlled burning of current cryogenic systems. Pulse detonation provides the best option for a revolutionary technology push in conventional rocketry using unconventional physics. The system produces 15 percent higher I_{SP} than conventional cryogenic systems with 40 times the decrease in feed pump pressure, which contributes to weight reduction and increased operational efficiency.[4] This system also provides an alternative to chemical propulsion by using air-breathing technology where feasible as the vehicle transitions to orbit. These accelerator class engines transition the subsonic, supersonic, and hypersonic regimes to Mach 25 with each engine variant operating within its most efficient regime.[5] Using laser technology, the LPD engine can transition to the electric MHD fan-jet engine in the final push to orbit.[6] This propulsion system uses the earth's magnetic field to produce energy for ionization of gases in the upper atmosphere or in an onboard propellant and accelerates these gases through a hypersonic fan jet for thrust generation. The MHD engine theoretically produces 6,000–18,000 seconds of I_{SP} for acceleration to velocity greater than Mach 25. Technology pushes in high-temperature superconductors, laser wave detonation, and compact, lightweight, high-energy generation devices are required.

High-Density Fuels

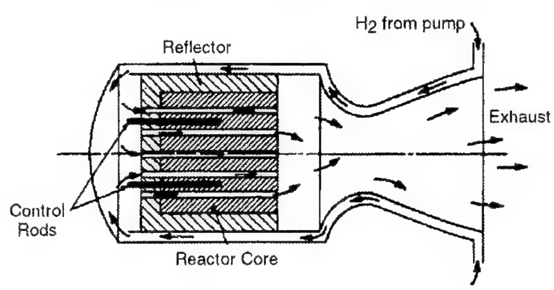
This program, currently titled the "High-Energy Density Materials Program" (HEDM), is a concept to increase the energy content in conventional chemical bonds of nonnuclear fuels.[7] For example, a 5 percent boron additive to solid hydrogen is projected to produce a 107-second I_{SP} improvement in efficiency, and other additives such as titanium and boron/titanium composites show promising results.[8] This trend results from the continuation of study suggested by *New World Vistas*. This program possesses high potential in the search for metastable fuels, which are reasonably stable and practical. Future environmental considerations must be factored into their feasibility. This increase in I_{SP}, due to higher chemical release over the chemical maximum of 450 seconds, could result in a payload increase of 22 percent. Currently, the most promising research is in metallic hydrogen/oxygen propellants. The synthesis of these highly energetic propellants is the technological challenge, but the rapid increase in computational modeling could drive the concept toward reality without large capital investment in research and development.

Nuclear Fission

This concept has been developed extensively through the 1960s and 1970s. It has the advantages of I_{SP} greater than 1,500 seconds, and the fuel mass fraction is much smaller with an associated compact fuel geometry due to high-fuel density. Moreover, it works easily in space, because the reaction requires no atmosphere. In nuclear thermal propulsion, a propellant gas is heated as it flows through the core of a reactor and is then expanded and expelled through a nozzle (fig. A-1). The reactor core can be solid, liquid, gas, or plasma. The last two approaches can produce high

temperatures and greater efficiency but are limited to space orbital applications due to the expulsion of radioactive gases. Project Rover directed by Los Alamos National Laboratory produced a solid core engine that produced 200,000 pounds of thrust with 9,500 kilogram reactor mass and an I_{SP} of 845 seconds.[9] Therefore, the concept has been proven in theory and practice. Further, dual-use designs can be developed which provide electrical generation and ion drive maneuvering power after the propulsion phase is complete. Finally, the technician-driven infrastructure is proven since Naval Reactors have trained personnel to operate reactors with automatic controls at the "blue-suit" level safely for years with a well-established training and maintenance record. Recent NASA research on the lunar-augmented nuclear thermal rocket combines a scramjet with near-term nuclear thermal rocketry and demonstrates the utility of this concept.[10]

The largest obstacles to nuclear rocketry are both political and environmental. Radiation shielding is required for human and payloads and adds significantly to the vehicle mass fraction. There is some inherent fuel erosion due to the velocity and hot temperature of the propellant, which causes ejection of fission products into the exhaust. Improvements in metallurgy since 1973 could correct this problem by using improved cladding, different propellant gases, or more efficient fluid regimes (detected through computer-aided design). Finally, uncontrolled reentries or launch failures result in nuclear material entering the environment either intact, in pieces, or dispersed as fine particles. Offsetting this problem is the fact that the reactor mass is small by comparison and would result in little or negligible environmental impact, and remote launch sites could further reduce the risks.



Source: Air Command and Staff College, "High Leverage Space Technologies for National Security in the 21st Century" (Maxwell AFB, Ala.: Air University Press, 1995).

Figure A-1. A Basic Nuclear Thermal Rocket

For reusable vehicles, disposal of spent fuel adds to the commercial problem. Current commercial reactor designs have significant safety features built into them; nuclear reactors do not exchange by-products with the environment, and the integral fast breeder reactor technology, demonstrated by Argonne Laboratory, is inherently safe and utilizes plutonium and by-products as fuel.[11] The spent fuel is the largest storage problem due to long-lived radiation products. Recent technological advances could make this problem a non-issue. These include permanent subterranean/seabed storage in stable geological formations in glass-encapsulated canisters, Argonne Lab's nuclear transmutation, which reduces long-lived radioactive isotopes to less radioactive ones through high-intensity nuclear bombardment, and shooting the waste into the sun, the moon, or deep space, which could expand the launch market.[12]

With over 200 years in Uranium resources and as the world's largest consumer of energy, the US may intensify its commercial nuclear industry by 2025 and educate Americans regarding its benefits. Realistically, this scenario is remote currently or for the future. Moreover, public disposition would not allow the development of a nuclear fission, earth-based, space propulsion system which is used within the earth's atmosphere. Conversely, satellite history has demonstrated the application of nuclear power in space-based vehicles.

Fusion

In the realm of plasma physics, nothing dominates it as the quest for commercial-fusion power. For propulsion, the laser-fusion

concept, which is compressing a deuterium-tritium fuel pellet with symmetrically positioned lasers for a few billionths of a second until the nuclei fuse gives off the heat, is the most promising. In magnetic fusion, the fuel plasma is suspended in a magnetic field and heated until temperature and densities are achieved for the nuclei to fuse. Sustained reactions of one second have been demonstrated, but nuclei reactions with contaminants, lack of plasma-heating technology, and beam constraints have prohibited commercial application. If the technological difficulty of being able to vector the energy can be achieved or the energy can be harnessed in a working fluid, a propulsion engine without the long-lived radiation of fission could be designed for space applications. Recent research at the University of Michigan conceived a simple magnetic mirror confinement system to create a high-plasma density, which theoretically could produce a propulsion system with an I_{SP} of 100,000 seconds.[13] Continued advances in computer technology for plasma modeling, high-temperature superconductors, and charged particle beams could provide the technology leap to produce a self-sustaining fusion reaction by 2025. Current projections place commercial fusion applications at the year 2045.[14] This application of fusion to a propulsion system is a third generation system, which opens the solar system to an operationally strategic area.

Third Generation Propulsion Possibilities

Antimatter Drive

Early in the HEDM program, matter-antimatter annihilation was considered a possible propulsion fuel source. The theory is simply that antiprotons and positrons would be slowed, trapped, and recombined to form a charged antihydrogen cluster. This cluster forms one part of the bipropellant fuel and the other ordinary hydrogen. The antimatter cluster is reacted with the ordinary hydrogen and is almost completely converted to energy. Similar to nuclear reactions, the antimatter reactions swap rest mass energies, releasing energies 1,000 times greater than nuclear reactions.[15] The concept is simple, but practical implementation is beyond current technologies, since any fuel must be able to be produced in quantity, stored, reacted in a controlled manner, and energy vectored in a useful form. While small quantities of antimatter have been produced, the current capability is 12 orders of magnitude below required production. Recent research at Pennsylvania State University demonstrates a promising propulsion system based on antiproton catalyzed microfission/fusion, with their recent completion of a portable Penning Trap, which captures antimatter particles for storage. This propulsion system uses the energy release from the antimatter reaction as the catalyst for a controlled microfission detonation (small vectored nuclear explosions) to produce thrust. The Penning Trap is being transferred to Phillips Lab at Kirkland AFB, New Mexico for use in demonstrating microfission in late 1997.[16] The radiation and environmental considerations are less than nuclear fission propulsion, but the high temperature would require sophisticated magnetic containment (similar to fusion) to avoid a meltdown catastrophe. A technology leap in particle physics and magnetic containment is required to implement this technology.

Quantum Fluctuations/Space Drive

Recent theorists have proposed a particle theory for inertia and gravity.[17] This theory proposes that space is not empty but a "cauldron of seething energies," known technically as quantum fluctuations or Zero Point Energy, which have been detected but not tapped. Arthur C. Clarke points out that the potential impact on civilization would be incalculable, because the fuel source would be available to all infinitely and all fuel technologies and concerns over environmental impact would be obsolete.[18]

Harnessing this technology requires the same technology leap in particle physics as antimatter and is considered remote by 2025.

Orbital Transfer Vehicle Propulsion

The 2025 military OTV employs second generation combined propulsion systems. A nuclear-electric ion drive combined cycle enables high maneuverability with maximum time to refueling. Commercial OTVs use solar-electric ion drive for economical maneuvering and thrust, augmented by improved fuel cell technology for minimum high-thrust requirements.

Combined Cycle OTVs

Nuclear/Solar Electric Ion Drive

Solar energy is infinitely available in space, but its energy density is small compared to other earth-born sources. It dissipates exponentially as one travels outward from the solar system. Consequently, its required space and mass fraction is large even for electrical generation. Nuclear thermal reactors have large-generating potential, but carry radiation, environmental, shielding, and public support problems. The space-based application of nuclear power has the history to overcome these difficulties. The use of nuclear or solar power for electrical generation enables a propulsion system that ionizes a nonreactive gas, in which the positively charged ions are pulled out of the engine, forming a jet that impels the craft forward. This way, unlike chemical propulsion, the energy generation and momentum are separated. It has the advantages of speed, efficiency, and economy as the current laws of physics allow. Refuelable fuel cells and thermionic reactors augment the power source requirements during high demand. Current research on Russian Express spacecraft with stationary space thrusters and on the Hughes Galaxy III-R communications satellite are the first tests of ion drive principles.[19] Moreover, NASA's millennium program for interplanetary exploration is proposing use of solar-electric ion drive.[20] Nuclear ion drive enables responsive orbital maneuvering (with adequate thrust-to-weight ratio not available from solar energy) required for space mission accomplishment.

Third Generation OTV Propulsion Systems

Magnetohydrodynamic and Laser Propulsion

Magnetohydrodynamics has the immense potential of I_{SP} in the range of 10,000 seconds. It derives its energy by using space magnetic field energy and converting it to electricity to drive a laser-propulsion system on the vehicle. Current research tested a magnetoplasmadynamic thruster on the Japanese Space Flyer Unit, and it showed promise.[21] The major disadvantage is the large mass fraction of the vehicle to provide power for thrust requirements of major propulsion. A technology leap in superconductors and plasma physics is required before this technology is practically feasible. Laser propulsion is similar to ion drive, but a ground-based laser imparts energy to a working fluid (hydrogen) at a high I_{SP} (1,500 sec). A technology leap in laser physics with regard to atmospheric compensation is required. Further, the system requires a large ground-based infrastructure for vehicle tracking, a complicated design, and a large power generation requirement.[22]

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Spacenet: On-Orbit Support in 2025

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Executive Summary

In 2025, on-orbit support will be vital to employing space assets as an instrument of national power. Four areas of on-orbit support need to be developed over the next three decades to ensure that the US maintains space dominance. These four key areas together form the Spacenet 2025 system. This white paper examines these four areas in the context of supporting space assets, not the particular missions the satellites may accomplish.

First, support to the war fighters will be the priority of the military space program. The theater commander requires reliable, timely support from space to utilize all war fighting assets. This space support includes communications, navigation, weather, missile launch warning, and data transfer. Although intelligence is not addressed in this report, on-orbit support provides sufficient processing, storage, and transmission capability to fully support the intelligence architecture. In essence, the war fighters in the field will not need to worry about overloading voice or data channels—the required capacity will be available continuously.

Second, the satellite command, control, and communication (C^3) system must be responsive enough to position satellites in the correct orbits to support the theater commander. This requires: C^3 systems to control satellites over the horizon from the ground control station; automatic, redundant switching to ensure that a particular satellite receives the correct commands; and flexible, secure, and mobile ground stations. Satellite autonomy is the ultimate goal; ground control when required, is minimized.

Third, satellite design is critical. Improved design lowers cost, increases flexibility, and enhances survivability. Key design considerations include satellite size, longevity, power and propulsion requirements, radiation-hardened electronics, satellite autonomy, and satellite disposal. Quantum leaps in information systems technology will lead the design environment, but adapting system capabilities to operate in space is a major stepping stone to achieve Spacenet 2025 capabilities.

Finally, space assets must be survivable in a hostile space environment and immediately replaceable if destroyed. Satellite security employs both passive and active defenses to counter manmade and environmental threats such as space debris, antisatellite (ASAT) systems, or meteorites.

These four areas of on-orbit support are the pillars of the Spacenet 2025 system. This "Internet in space" depends on the four pillars to provide timely data and support to war fighters worldwide, seamless C^3, and carefully designed satellites that are survivable and secure. The Spacenet 2025 system synergistically builds capabilities so the whole Spacenet 2025 system is greater than the sum of its parts. Spacenet 2025 may become the ultimate force enhancement and projection system, ensuring that the US remains the world's sole superpower throughout the twenty-first century.

Chapter 1

Introduction

Alfred T. Mahan recognized the importance of lines-of-communication (LOC) in the vastness of the earth's oceans. One of the Navy's missions was to protect merchants traveling those sea LOCs. Additionally, "The government by its policy can favor the natural growth of a people's industries and its tendencies to seek adventure and gain by way of the sea."[1]

US airpower and spacepower doctrine should follow a policy favoring the natural growth of space industries and promoting the security and safety of these commercial ventures. Research and development, policies, and guidance of a large-scale satellite C^3 backbone system, used by both commercial and military sectors, will enhance the safety of the LOC for spaceborne platforms.

In 2025, space operations will be a vital instrument of national power. On-orbit support will help determine the effectiveness and efficiency of space operations. This paper describes the desired operating methods of on-orbit support to ensure the US remains the dominant space power in 2025 and beyond. Specifically, the scope of on-orbit support in this paper begins with satellite release from the launch vehicle and ends with satellite disposal at mission termination. Launch operations and specific missions of space assets are the subjects of other papers in the ***2025*** research project and are referenced in this paper but are not specifically addressed there.

Two assumptions form the essential basis of this report. First, the US will be a dominant world power in 2025. Second, space assets and operations will increase in importance both militarily and commercially. In fact, commercial enterprises will lead the development of some space technology. As DOD continues downsizing, virtual presence from space will replace troops as the vehicle for forward presence. On-orbit support is the enabling function for the global awareness necessary to maintain US space dominance.

Four pillars describe the Spacenet 2025 on-orbit system. The first pillar is the war fighter's requirements. The second pillar is command, control, and communications (C^3) of space assets—the method of satisfying the customer. Spacecraft design is third with a focus on satellite size, service life, power and propulsion requirements, radiation-hardened electronics, autonomy, and satellite disposal. The final pillar is satellite security in the context of manmade and environmental hazards.

The end-state goal is for on-orbit support to be transparent to the user: responsive, effective, and unobtrusive. The Spacenet 2025 system will meet the challenge.

Note

1. Alfred T. Mahan, *The Influence of Sea Power upon History* (New York: Dover Publications Inc., 1987), 82.

Chapter 2

Required Capability

The roles of the US military in 2025 will likely span the entire spectrum, from internal security and deterrence of major conflict to military operations other than war. The alternate futures of 2025 may find the advancement and growth of technology either constrained or exponential.[1] Even with constrained growth in 2025, technological advancements in the next 30 years will be significant. If the US military hopes to remain the world's premier deterrent and fighting force in 2025, it must take advantage of technological advancements to improve on-orbit support.

In 2025, war fighters will operate in an information-rich environment. Both commercial and military sources will provide this abundant information and adversaries will probably exploit the commercial information opportunities. This trend is readily visible today with the commercial sale of 10-meter resolution imagery from the French *system probatoire d'observation de la terre* (SPOT) satellites, the explosion in commercial communications ventures, and worldwide commercial use of global positioning system (GPS) navigation signals.

Space will be the medium of choice for information collection and dissemination in 2025. The unique capabilities to operate freely at any point above the earth, communicate with other satellites and ground personnel "over the horizon" (using satellite cross-linking), and near simultaneous dissemination of information to numerous users make space systems the premier force-enhancement capability.

If space force enhancement data is widely available commercially, will there be "parity" between nation-states or groups with enough money to buy and exploit this data? Absolutely not—the key will be to quickly gather huge masses of information, assimilate it, and act accordingly.

On-orbit support is a key requirement to deliver the core competency of space dominance. Within on-orbit support, four areas provide the basis for investigating required capabilities for satellites in 2025: support to the war fighter, C^3, satellite design, and satellite security.

To support the US war fighter of 2025, satellite systems must tighten the US's observe, orient, decide, and act (OODA) loop (fig. 2-1) to stay well ahead of the adversary's capabilities.[2] This does not mean simply supplying truckloads of data to whomever has time to read it; the war fighters of 2025 need information that is critical to the particular mission and they need it at the optimum time. In a high-technology environment the dangers of information overload are real. Information overload must therefore be avoided.

Satellite C^3 is another required capability. C^3 must be simple, cost-effective, and robust. Communication from earth-to-space or earth-to-earth using satellites is another key to "tightening" the OODA loop. Additionally, increased weapon lethality and miniaturization necessitates the designing of more survivable satellite C^3 systems.

Satellite design is another key link to achieving space dominance. Space systems must be smaller, more cost-effective, and more responsive to the customer's needs. Today's propulsion fuel and satellite electrical power, limitations, and the susceptibility of electronic components to space radiation, satellite autonomy, and satellite disposal require revolutionary directions to fully "operationalize space." Solutions to these satellite limitations should also drive costs down so that more money can

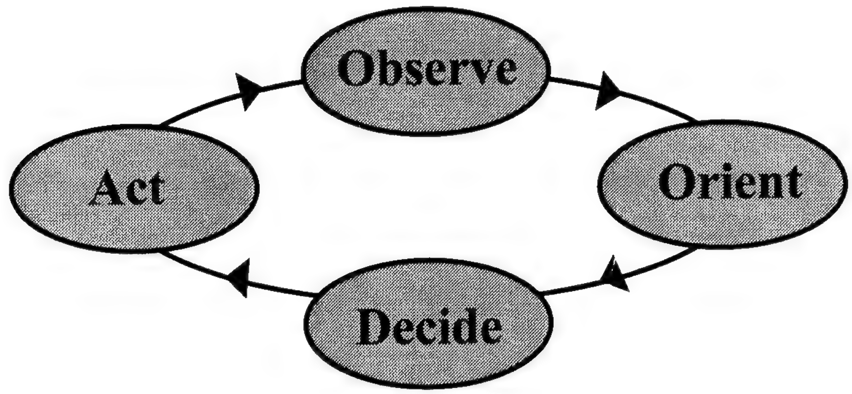


Figure 2-1. Observe, Orient, Decide, and Act (OODA) Loop

be spent on the "shooters," rather than their supporting platforms in space.

Given the criticality of space support to the war fighters of 2025, the proliferation of commercial satellites, and other nations playing the "space game," satellites become increasingly high-value targets. Satellites in 2025 must employ inherent countermeasures to ensure US space dominance. The solution is not to give satellites armor like M-1 tanks, but to employ active and passive countermeasures where they make sense. If all else fails, plan for attrition—and for recovery of lost capabilities with timely satellite replacement.

On-orbit support is the linchpin to maintaining US space dominance in the 21st century. Aggressive developments in war-fighter support from space, satellite C^3, design, and security will form the building blocks of the Spacenet 2025 system to meet the requirements and solidify US space dominance in 2025 and beyond.

Notes

1. Air Force ***2025***. Alternate Futures white paper. ***2025*** database (Maxwell AFB, Ala.: Air War College/ ***2025***, 1996).

2. 1st Lt Gary L. Vincent, "In the Loop in Command and Control," *Airpower Journal*, Summer 1992, 17–18.

Chapter 3

System Description

A coming information revolution and its impact on the battlefield is a popular topic for military theorists today. Many considerate it a revolution in military affairs (RMA)[1] while others simply consider it an evolutionary change that exploits information with technology. The issue is a proper subject for debate. What is not debatable is the fact that war fighters and peacekeepers of the future will operate in an information-rich environment and must possess the technical means to obtain and exploit information in near real time.[2] One Chinese defense expert described future wars this way: "In hi-tech warfare, tactical effectiveness no longer depends on the size of forces or the extent of firepower and motorized forces. It depends more on the control systems over the war theater and the efficiency in utilizing information from the theater."[3]

The War Fighter's Requirements

The need for accurate information is critical to war fighters and peacekeepers. War fighters must obtain accurate information faster and immediately employ it with decisive results. Accurate information helps penetrate the fog of war and decreases the risk. Fighting and winning in 2025 will hinge upon accurate and timely assimilation of vital information from space. War fighters will operate in an information-rich environment as countless terabits (10^{12}) of information will flood the theater of operation. Some of this information will be critical and some of it useless. The key will be separating the "wheat from the chaff" quickly to facilitate a "good" decision.

The availability of data from both commercial and military sectors can and will place information in the hands of adversaries, potentially disrupting or denying US objectives. This data will serve as a catalyst, allowing adversaries to shrink their OODA loop.

In 2025 the amount of observed data may reach parity between opposing forces, making the "observe" step of the OODA loop a "dead heat." However, through exploitation of the "orient" step (via on-orbit and in-theater processing), the US OODA loop can tighten well inside that of any potential adversary (fig. 3-1). With the critical information identified first, US war fighters can "decide" and "act" well before adversaries can remove the "chaff."

History has shown even the most accurate information is useless if not given to the war fighter in a timely manner (just-in-time) or on-demand. A prime example of accurate intelligence with egligible results was the Scud hunting missions during Operation Desert Storm. In all, coalition forces launched 2,493 sorties[4] against an estimated 225 Scud transporter-erector-launchers (TEL).[5] To date, there is no evidence that any TELs were destroyed. Evidence confirms the destruction of decoys, trucks, and objects with Scud-like signatures despite the fact that space-based assets immediately detected launches of Iraqi Scud missiles.[6] Within minutes, theater commanders were notified of the launch and aircraft was scrambled or diverted to the launch site. In the few short minutes it took to process and communicate the data, the TEL had vacated the launch site. Authorities estimate that an Iraqi missile crew could launch, drive off, and conceal a TEL in five minutes.[7] In future battles involving chemical, biological, and nuclear weapons, these five minutes could be the difference between victory and defeat. In 2025, time-critical information

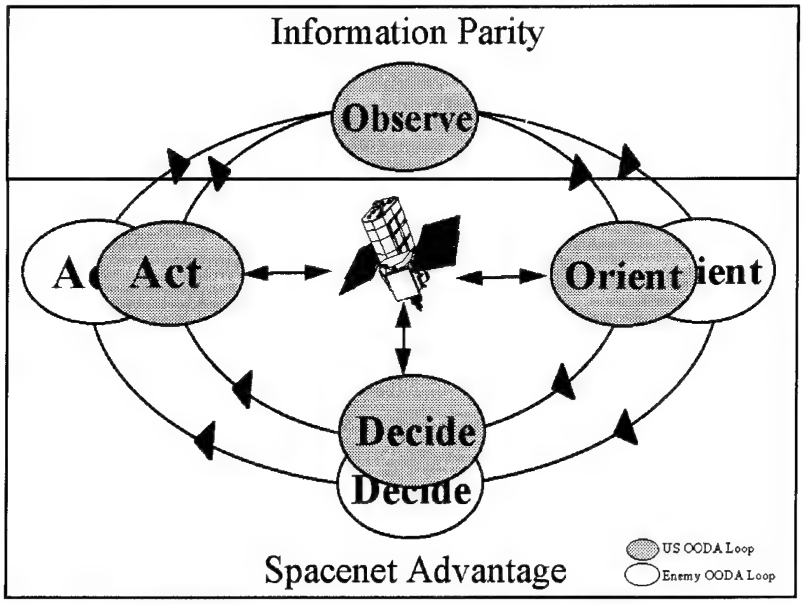


Photo from Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corporation

Figure 3-1. The Impact of Spacenet on the US OODA Loop

will have to travel the shortest possible distance, directly from the satellite to the war fighter.

A war-fighting commander's goal for information is to have it in the right hands at the right time, on-demand. Delays for processing are unacceptable. In 2025, war fighters will rely heavily on preprocessed, archived data, and rapid dissemination of new or custom information.

On-Orbit Processing

The keys to controlling information are the quantum increases in the speed and capacity of information-processing systems and the ability to move processing and correlation functions into space. Equally important is the integration of hardware, software, and information from the commercial sector.[8] On-orbit processing of data and the resulting rapid distribution of critical information to the individual war fighter, just-in-time or on-demand, is a vital step in maintaining land, air, and space dominance. As technology advances, the feasibility of automating data collection, fusion, and distribution becomes a reality. Recent events, such as the bombing of the World Trade Center in New York City and the federal building in Oklahoma City, show some of the vulnerabilities of fixed ground facilities. Satellite control facilities may be better protected, but are only somewhat less vulnerable. The combination of technological advances and vulnerabilities will necessitate dispersing many information processing functions to the next high ground—space.

In order to increase the speed of dissemination, information from space-based assets must be available to all levels of friendly combatants. Every war fighter, from the joint force commander (JFC) to the soldier in the field, must have access to critical information on-demand and in near real time. Advances in computer processing speed, artificial intelligence software, data storage, and power supplies will enable on-orbit processing. Direct links from the satellite sensor to a cockpit, a foxhole, or a warhead are a necessity in 2025.

Exploitation of information at the lower levels will require user-friendly, battlefield savvy systems that allow the company commander, the squad leader, the pilot, or the officer at the helm to access and assimilate critical information quickly. These man-portable systems will interface directly with on-orbit assets and with mobile theater control centers. Predetermined information requirements based on the need-to-know will allow in-theater and on-orbit archiving and updating of prepackaged, fused information. Wide bandwidth transmissions that allow two-way communications are a necessity. Additionally, the user must have the option to request modified data in near real time as the battlefield situation changes, enabling operations well within the enemy's OODA loop.[9] Several emerging technologies will make on-orbit processing feasible.

Artificial Intelligence

The heart of any processing system is the software. There will be a fundamental shift from programming computer actions to allowing computers to serve as a thinking agent, anticipating needs based on preprogrammed criteria and real-time inputs from the war fighter. These new programs or "software agents" are a major step toward artificial intelligence.[10] 2025 software will adapt and evolve just as organisms mutate in order to adjust to environmental changes.[11] Individual war fighters will be data-linked to a space-based processing center and their every action will be recorded by software agents. These agents will use these real-time inputs to analyze, anticipate, and predict what the war fighter will need. The software agents will then coordinate in cyberspace with spaceborne collectors and ground-archived data-processing nodes to prepare a fused information package for the war fighter. Time-sensitive information will be pushed to the war fighter. The software agents will also have the ability to update archived data to ensure "freshness."

Archiving Data

Information-processing in space will require tremendous leaps in the storage capacity of "hard drives," not to mention a reduction in their weight. Just 10 years ago, a 10-megabyte personal computer hard drive cost approximately $2,500; today, 100 times more memory costs less than $300. Today's research indicates that the future of information storage is in optical systems. Budding technologies such as holographic data storage systems (HDSS) will exponentially increase the ability to archive and retrieve data. HDSS has several key features that make it ideal for space and field applications: it is lightweight, has tremendous capacity for storage, allows exponential increases in throughput, and has no moving parts.[12] HDSS offers the possibility of storing trillions of bits of information on a disk the size of a small coin.[13] The system employs lasers and an optical data-storage medium. These high-capacity, high-bandwidth storage devices can be accessed in parallel, achieving throughput rates approaching one gigabyte per second[14]—or maybe better—by 2025.[15] With this storage capacity on-orbit and in-theater, archived information is available when needed by the war fighter.

Data Compression

To further multiply the value of HDSS, new technologies in data compression are being researched. For example, imagery products require a large amount of storage space and are ideal for compression. When imagery is decompressed, however, it loses resolution relative to the amount of compression it underwent. Fractal compression research offers high compression rates and high resolution after decompression. This new technology converts imagery to mathematical equations and then looks for redundancy in the equations.[16] By noting these mathematical similarities, the data is then compressed and decompressed accurately. Initial compression rates from 20:1 to 50:1 are

possible with no appreciable loss of resolution.[17] Fractal compression has one additional benefit; imagery will update itself as it skews, moves, or rotates.[18] This will enable near real time detailed video updates.

Command, Control, and Communications

The missions of airpower and space power in 2025 will still be to win wars. The primary reason for maintaining a military establishment will remain the same as it is today: to protect vital interests and provide security. To maintain air and space dominance over the next three decades of shrinking budgets, the *New World Vistas* study recommends the military outsource capabilities that are not considered core competencies.

Telecommunication is one area the *New World Vistas* study recommended for commercial outsourcing.[19] Military telecommunication using commercial systems is a trend underway today. Air Force Space Command (AFSPC) currently leases commercial communications satellites, aptly named Leased Satellite Communications System (LEASAT) by their owner, Hughes Communications.[20] AFSPC uses LEASAT to transmit satellite command and control (C^2) information, along with mission data, from remote satellite tracking stations to the satellite control facilities at Falcon AFB, Colorado, and Onizuka AFS, California. Army Special Forces units will begin operational use of commercial mobile satellite communications technology in 1997.[21] The Navy uses commercial communications satellites such as International Maritime Satellite Organization (INMARSAT)[22] for communications with ships at sea. As this trend grows, it will affect communications on earth and in space.

Communications systems will be a vital force multiplier for war fighters. The fiber-optic backbones that MCI, Sprint, and AT&T are installing in the 1990s have "advantages for heavy-volume point-to-point traffic, whereas satellites will continue to be cost-effective for multipoint and thin route services."[23] Translated into military terms, terrestrial communications work well in-garrison, but satellites provide less expensive communication to fast-moving mobile units.

Communication satellites currently provide a significant portion of DOD communications. Additionally, the 1996 draft "Air Force Executive Guidance" assumes that "US reliance on space-based capabilities will continue to increase" and "the number of national and non-national entities utilizing space-based assets to gain advantage will increase."[24]

Spacenet—The Internet Deploys to Space

Given the trend towards using space-based commercial telecommunications and its impact on the war fighter, the Air Force should maximize use of commercial systems to meet military requirements. To focus the research and development required, the Air Force should encourage the development of Spacenet, a generic spacecraft C^3 system to meet C^3 needs and enhance interoperability in 2025.

One component of spacenet is a backbone communications system that allows scaleable, survivable, and flexible response to user needs. The concept of operations for the backbone is similar to that of orbiting Internet nodes. Orbiting communications spacenet nodes—switches in space—transmit information packages to other communications switches. Multiple orbiting switches route packets efficiently by tracking the different paths available to the final destination. Paths to destinations can be through other orbiting switches or terrestrial communications links. The network of orbiting switches expands easily—new switches identify themselves to switches already in the network, and their address is passed throughout the network. As orbiting switches degrade or "die," operating switches detect the failure and route packets around the problem switch.

Packets receive appropriate priorities for transmission based on priority tables uploaded by ground controllers.

Spacenet strongly supports the principles of command, control, communications, and computers (C^4) (table 1).[25] The backbone communications system is flexible enough for spacecraft C^2 and transfer of mission data into and from space. The system must have sufficient capacity to take control of all essential space assets during a contingency.

The analogy of an Internet in space extends beyond technology into the concept of operations. The Internet was originally developed as a military system, called the Advanced Research Project Agency Network (ARPANET) for survivable communications in a nuclear environment. Spacenet provides a survivable communications architecture for space systems. The Internet has grown because of commercial use; it is more cost-effective to hook into Internet than to lay dedicated data-communications lines. Spacenet will grow with commercial use because it will be more cost-effective for commercial entities to hook into a large, flexible C^3 system for spacecraft rather than build another C^3 system. The military benefits from the commercial growth of spacenet because the larger system provides more communications capacity and has more survivable nodes. Similarly, the military utility of spacenet will grow through commercial additions. Table 2 compares today's Internet with the 2025 Spacenet.

A fundamental question to answer is: why have an Internet in space? The terrestrial Internet can reach most locations on earth that have telephone access. However, the terrestrial Internet system does not extend out to space assets. Current US space operators communicate with space assets through a limited number of fixed, vulnerable ground antennas.

Another reason for spacenet is that the world of 2025 may need to support remote information users in the air and in space. Just like the transoceanic telephone system communicates on earth, space-based users will need a communication system to send information to or get information from the earth. Several of the 2025 systems, including those proposed in the *Counterair* paper and the *Unmanned Aerial Vehicle*

Table 1
C^4 Principles and Criteria versus Spacenet

C^4 Principles and Criteria	Spacenet Support for the Principles
Interoperable	A backbone communications system, providing interoperable space and terrestrial communications
Flexible	Communication anywhere in the solar system; expanding as humanity's reach expands
Responsive	A reliable and redundant method of communication
Mobile	Available anywhere in the solar system (as the spacenet is expanded) through mobile terminals
Disciplined	Provides control methods to prioritize communications
Survivable	Multiple interconnected nodes allow graceful degradation if nodes fail
Sustainable	Financed primarily through commercial ventures

Table 2
Similarities of Terrestrial Internet and Spacenet

Similarity	1996 Internet	2025 Spacenet
Military Use	Originally developed by DARPA for Cold War communication	Developed for cost-effective, survivable, mobile communications solar system-wide
Commercial Use	Commercial terrestrial information transfer	Commercial solar system-wide information transfer
Hub/Spoke Architecture	Easily expanded, using industry standard protocols	Architecture allows expansion with new nodes to add capacity or reach other parts of solar system
Concern with Results, not Technologies	1996 user does not need to know Internet communications architecture—it just works	2025 user does not need to know spacenet architecture

paper, call for using a space-based C^3 system. Spacenet fills the C^3 void as an inexpensive, standardized system for providing communications to a multitude of terrestrial, airborne, and space-based military systems.

Spacenet complements the terrestrial communications system as a more cost-effective alternative to provide connectivity for remote and mobile users. "Fiber-optic costs per circuit-mile are high for low utilization but decline rapidly as the number of circuits increases; satellite costs per circuit-mile are lower at low utilization but decline more slowly."[26]

Advances Required for Spacenet

The operational environment in 2025 could pose a number of obstacles that a robust space-based C^3 system must overcome. Current technologies must grow to meet the requirements of the 2025 operational environment. Emerging systems must mature and improve.

Tables 3 and 4 compare the increase in data throughput of terrestrial versus space-based telecommunications transmissions media. In 1996, terrestrial telecommunications transmission capabilities have outstripped the capabilities of satellite systems. In 2025, satellites may still only carry a fraction of the total solar system's telecommunications traffic, but that fraction must provide more throughput than possible today.

SPACECAST 2020 proposed that information needs in the future will be driven by user demand, pulling information from the source when needed as opposed to pushing information at a constant rate. Users will require high data transfer rates to support demand for large quantities of information. Current technologies do not support the data rate required by future users. In 2025, a mixture of extremely high-frequency (EHF) broadcast radio communications and high-bandwidth pinpoint laser communications will meet the need for higher data transfer rates.

Current radio-based communications systems interfere with each other if not closely coordinated. For example, the super high-frequency (SHF) Air Force satellite control network uplink and downlink frequencies are protected by the Federal Communication Commission (FCC) in the US, but these frequencies are allocated to commercial satellite systems in Europe.[27]

Table 3
Throughput for 1996 Satellite Systems

Satellite	Throughput Rate
MILSTAR II Satellite	49MB/sec[a]
Defense Satellite Communication System	100MB/sec[b]
Advanced Communication Technology Satellite	220MB/sec[c]
Tracking and Data Relay Satellite	300MB/sec[c]

Sources:
[a]Capt Michael L. Figurski, Milstar Engineer, 4th Space Operations Squadron, telephone interview by Maj Carl Block, 23 February 1996.
[b]1st Lt John Giles, Squadron Defense Satellite Communication System Engineer, 3d Space Operations Squadron, telephone interview by Maj Carl Block, 23 February 1996.
[c]Andrew Wilson, ed., *Jane's Space Directory, Eleventh Edition 1995–1996* (Alexandria, Va.: Jane's Information Group, 1995), 361.

The EHF band is relatively empty compared to the clogged SHF communications band. Moving to EHF reduces the interference problem for the short term. However, when EHF frequencies become standard, interference may affect EHF bands as well.

The US currently has only three antennas used to control deep space satellites.[28] These antennas are barely able to support current deep space projects; they will certainly be unable to support the large number of future satellites which will be used in other parts of the solar system. These deep-space satellites may come as commercial asteroid mining ventures or military satellites patrolling the solar system.[29] Moreover, if a planetary defense system is developed, the current C^3 system clearly cannot support it. Future requirements demand an upgrade to the current satellite communications backbone. The current satellite C^3 infrastructure will not meet future demands of satellites in earth orbit or beyond.

The satellite communications backbone must be capable of handling large fleet operations from the postlaunch phase through satellite disposal. The system must provide for C^2 of the spacecraft, in addition to transmission of mission data back to the user. Additional capacity could be used to transfer information packets from one

Table 4
Throughput for 1996 Terrestrial Communication Systems

System	Throughput Rate
Fiber Distributed Data Interface	100MB/sec
Asynchronous Transfer Mode	622MB/sec
Fiber Channel	1064MB/sec
Fiber Distributed Data Interface Follow On	1250MB/sec

Source: Nathaniel I. Durlach and Anne S. Mavor, eds., *Virtual Reality Scientific and Technological Challenges* (Washington, D.C.: National Academy Press, 1995), 366.

terrestrial user to another. The backbone needs to operate with spacecraft in earth orbit or orbiting elsewhere in the solar system. Depending on deployment, the backbone will allow C^2 of spacecraft anywhere in the solar system.

Fiscal reality is a limiting factor; therefore, the system needs to be scaleable. Pieces of the system should fit into an interoperable architecture that allows incremental increases in the communications backbone. This allows implementation to meet the needs of the users and remain within budget. At the same time, it provides a framework for growth to ensure that previous investment is not lost when demands expand (the system can grow with the demand).

The system will operate with both commercial and military satellites, allowing cost sharing to minimize overall expense and encourage commercial development. Economies of scale will reduce the cost of common components. Opening the system to commercial users also makes upgrades less expensive since many users share the costs.

Advances in Earth-to-Space Communication Links

As the requirement to move more data through satellite communication channels increases, communication links will change from the current SHF frequency band to the higher EHF frequency band for communications between satellites and earth. In 1996, the DOD has two Military Strategic and Tactical Relay (MILSTAR) satellites using an EHF uplink and an SHF downlink.[30] EHF frequencies provide several benefits to both commercial and military customers (table 5).

Laser communication systems are a poor choice for communications between satellites and individual earth stations because of the laser signal attenuation caused by clouds or fogbanks. However, a number of spatially distributed earth stations, connected by high-speed terrestrial datalinks, could allow for laser communications between satellites and earth. "With three to five sites, 99 to 99.9 percent probability of a cloud- and fog-free line of sight to at least one station is possible."[31]

Advances in Satellite-to-Satellite Cross-Links

Relay satellites will become the norm for satellite control. By using relay satellites, the controller is not required to have the target satellite in view. NASA currently operates Tracking and Data Relay System (TDRS) satellites to demonstrate this concept. TDRS allows NASA to maintain communication with the space shuttle when it is out of view of the main NASA ground antennas. A more advanced constellation of relay satellites will allow users of spacenet anywhere in the world, or in the solar

Table 5
EHF System Advantages

Factor	Advantages to General Users	Specific Military Advantages
Small Antenna	Mobility	Inconspicuous
Highly Directional Signal	Decreased susceptibility to interference	Low probability of intercept
Large Available Frequency Range	Increased data throughput	Low probabilitiy of intercept and decreased susceptibility to jamming

Source: N. E. Feldman and Sharlene Katz, *Earth to Satellite Communications above 8 GHz, Features of Importance to the Military (U)* (Washington, D.C.: Defense Communications Agency, 1977), 46–47. (Secret) Information extracted is unclassified.

system, to contact an operational satellite. The relay satellite can then cross-link the signal to any other relay satellite to deliver the message to the intended operational satellite anywhere in the solar system (fig. 3-2). The constellation may use a packet-switching technology to ensure that appropriate signals are relayed to the correct satellites. A constellation of relay satellites provides for graceful degradation if one or more of the relay satellites fail, avoiding a single point of failure. Network control software distributed to each relay satellite will allow the network to adjust automatically to outages, rerouting information around degraded satellites and maintaining a constant level of service to operational satellites.

To minimize costs of launching and maintaining large numbers of satellites, standardized communications packages will be developed to interface with the spacenet. A limited number of models of standard communications packages will meet the requirements of large and small satellites. Limited models of the standard communications package allow simple, standardized interfaces between satellites. A simple, standardized interface makes troubleshooting easier as well.

The standard configuration package will use lasers for satellite cross-links. The communications laser will automatically evaluate the satellite system's orbital geometry and redirect information to the best satellite. For emergencies, the standard package will include an EHF radio transceiver to communicate directly with earth stations. The system also includes an emergency beacon to alert satellite controllers of a system failure.

Hardware and software onboard the standard communication package will provide automatic reconfiguration services, depending on the needs of the satellite. Communications automatically travel through the appropriate transceiver—laser or radio, depending on final destination. Intelligent materials will facilitate some hardware changes required to meet the on-orbit needs of the satellite's communications package.

Lasers will provide high-bandwidth communications capability between vehicles in space. Lasers have high data throughput and small transceivers. Since lasers provide

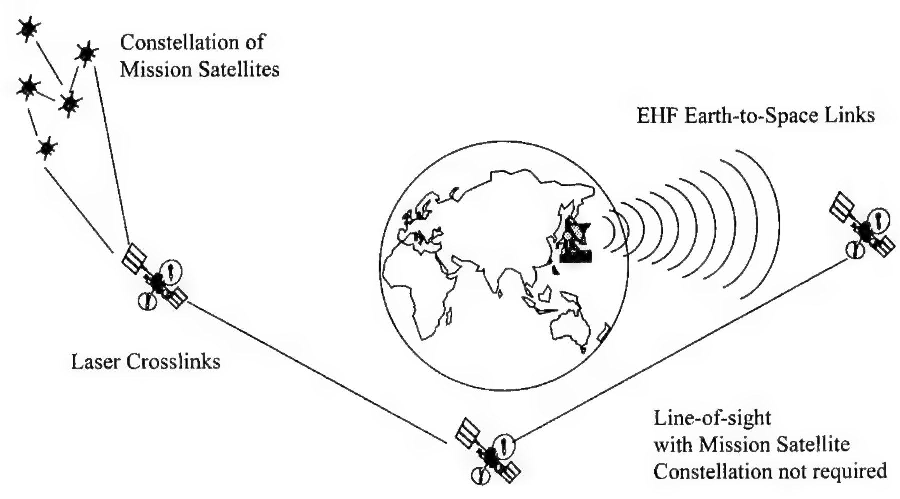


Photo from Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corporation. Photo from Federal Clip Art © 1995 with courtesy from One Mile Up, Inc.

Figure 3-2. Spacenet Telecommunications Links

line-of-sight communication, their signals will be difficult for an enemy to intercept.[32] The Air Force's Defense Support Program experimented with laser cross-linking between satellites in the 1980s. Unfortunately, the experiment failed because laser aiming techniques were immature. Subsequent systems such as the Air Force MILSTAR and GPS satellites use radio cross-links between spacecraft.[33]

Accuracy of laser aiming will improve with time, allowing laser communication between satellites by 2025. The Phillips Laboratory is working on phased arrays of laser diodes to steer lasers electronically. An experimental phased array is flying on the technology for autonomous operational survivability (TAOS) satellite today. However, improvements in aiming are required because the experimental package has a limited steering angle.[34]

The commercial market has been busy tackling the problem of stable spaceborne laser-aiming platforms. The Thermo Trex Corporation of San Diego, California, has introduced a new system called Lasercom.[35] Lasercom uses laser transceivers approximately the size of a bread box to communicate between satellites. Thermo Trex claims to have solved the problem of aiming spaceborne lasers by using beacons. The company plans to launch Lasercom onboard a military satellite in 1997.

In a system trying to avoid detection by enemies, beacons are clearly unacceptable. However, given the probable advances in phased array, laser-aiming technology[36] and microscopic machinery,[37] sufficiently stabilized platforms and laser-aiming systems should be feasible without using beacons by 2025.

Laser communication between satellites on orbit presents a number of opportunities. Lasers provide higher data throughput than today's radio frequency satellite cross-links. Lasers are directional and can aim at the intended receiver without fear of intercept. Wayward signals (known as side lobes) produced by radio-frequency antennas on today's satellites would be eliminated. Laser communications are easily manipulated by optical computers which are immune to electromagnetic pulse (EMP) effects.

Higher frequency lasers can increase available bandwidth for transmitting information in 2025. Future satellite communication systems will use visible light lasers. However, moving towards ultraviolet or possibly even X-ray lasers will increase the data transmission capability of the communications package.

X-ray lasers present special opportunities that warrant the extra effort to achieve this technology by 2025. X-ray lasers were first demonstrated at the Lawrence Livermore Laboratory in 1984. First-generation X-ray lasers were room-sized or larger. Slowly, the size of X-ray lasers is decreasing. Jorege Rocca, a physicist at Colorado State University at Fort Collins, Colorado, reports building an experimental table-sized soft X-ray laser in 1994.[38] Given the trend of electronics miniaturization combined with more sophisticated power supplies, there may be an operational X-ray laser small enough to fit on a satellite by 2025.

High-frequency lasers are ideal for satellite C^3 because of the vast increase in data-throughput on a single channel versus SHF band communication channels. A visible light laser has the potential for a thousandfold increase in data transfer capability over SHF communications. An X-ray laser has the potential for a millionfold increase over the communications capability of visible light lasers, giving the X-ray laser a billionfold increase over 1995 satellite communications capabilities (table 6).

Economies of scale ensure that standard communication packages will be less expensive than the custom communication packages used today. Some small moves towards standardization are now occurring. The International Telecommunications Union, a committee of the United Nations, allocates the frequencies used by satellites[39] in earth-to-space communications. Additionally, the Air Force Satellite Control

Network uses standard communications channels for satellite communications.

However, more than just frequency standardization is required. To make systems less expensive and take advantage of economies of scale, hardware must also be standardized. As satellites move towards increasingly reusable parts, the communications package will become more standardized.

One method of standardizing communications packages may be the combined use of microminiature machines[40] with intelligent materials to automatically adapt standard antennas to specific needs. Microminiature machines and intelligent materials can modify the physical properties of an antenna as needed for different frequencies or different transmission characteristics. Satellites requiring wide-beam broadcasting or a narrow pinpoint beam for data security can use the same antenna design.

Modification of antennas and optical lenses on-orbit to conform to the needs of the communication package requires the capability to build and modify on-orbit materials without human intervention. Intelligent materials offer the hope of building modifiable materials to meet the changing needs of systems. In 1995, NASA used electroactive materials to modify the optics on the Hubble space telescope.[41] Future advances should allow intelligent materials to be more useful in self-repair of on-orbit systems.

In those areas where intelligent materials are not sufficient or appropriate to modify equipment on-orbit, self-assembling materials built into the original communications package may provide the capability to regenerate damaged systems or create new systems. Self-assembly techniques were used in 1995 to build crystal semiconductor memories in an experimental environment.[42]

Table 6
Data Capabilities at Various Frequencies

Common Name	1995 Communications Use	Theoretical Maximum Data Transfer Capacity	Approximate Frequency Range
Ultra High Frequency	– Satellite Communication – Terrestrial Microwave	1.5×10^9 BPS	$300 \times 10^6 - 3 \times 10^9$
Super High Frequency	– Satellite Communications	15×10^9 BPS	$3 \times 10^9 - 30 \times 10^9$
Extremely High Frequency	– Satellite Communications	150×10^9 BPS	$30 \times 10^9 - 300 \times 10^9$
Infrared Radiation	– Experimental	150×10^{12} BPS	$300 \times 10^9 - 3 \times 10^{14}$
Visible Light	– Fiber Optic Communication	400×10^{12} BPS	$3 \times 10^{14} - 8 \times 10^{14}$
Ultraviolet Light	– Experimental	15×10^{15} BPS	$8 \times 10^{14} - 3 \times 10^{16}$
Soft X-rays	– Experimental	1×10^{18} BPS	$3 \times 10^{16} - 2 \times 10^{18}$
Hard X-rays	– Not Used	12×10^{18} BPS	$2 \times 10^{18} - 2.5 \times 10^{19}$

Sources: Ovid W. Eschbach and Mott Souders, eds., *Handbook of Engineering Fundamentals* (New York: John Wiley & Sons, 1975), 1057; and William Stallings, *Data and Computer Communications* (New York: Macmillan Publishing Company, 1988), 43.

Advances in self-assembly technology may allow on-orbit repair or replacement of degraded systems without human intervention.

Communication system repair could use self-assembling materials to refurbish parts on orbit. Self-assembling materials could continuously repair systems on-orbit, keeping the system fully mission capable. Should catastrophic system failure occur beyond the repair capabilities of the self-assembling materials, the system is replaced using black-box technology, where the entire system is simply pulled out and replaced.[43]

Driving Satellite C^2 into the Twenty-Second Century

The trend towards a multitude of satellites clogging earth orbits continues. Commercial communications entities will launch over 100 satellites before the turn of the century: Motorola plans to achieve initial operational capability of its Iridium® system with 66 satellites in 1997;[44] TRW launches the first of a 12-satellite constellation Odyssey® system in 1998;[45] Loral plans to complete its GLOBALSTAR® system with 48 satellites in 1999.[46] As the new century starts, the Teledesic Corporation plans to launch a constellation of 840 small satellites to transmit video starting in 2001.[47] These large constellations of satellites push the current state of the art in satellite C^2. Survivable mobile C^2 nodes with simple-to-use three-dimensional (3D) interfaces could greatly improve satellite control.

As a military system, spacenet must be survivable throughout the spectrum of conflict. The space and ground segments need to be survivable, since one is useless without the other. To enhance survivability of ground controllers, the system should not require line-of-sight communication with a mission satellite. Any uplinks or downlinks should have electromagnetic signatures that avoid disclosing the location of the ground controller or the mission satellite.

Survivable ground stations in 2025 will be mobile–both on and off the planet. To enhance mobility, systems must be small. This requires the computer used in the ground station to be small. It also requires a portable antenna to communicate with the satellite. The small mobile ground station should require a minimum of setup time to ensure all necessary operations begin immediately upon deployment.

To ensure maximum flexibility, the small mobile ground stations should not tie satellite controllers to large groups of satellite engineers. They should instead allow independent ground-control operations. The knowledge necessary to perform the satellite control mission will be resident in the mobile C^2 computer, avoiding the need to contact engineers to make decisions about satellites.

Software will replace the team of satellite controllers, orbital analysts, and engineers. The vast majority of routine operations will occur without human intervention. Human intervention is only needed for nonroutine operations and anomaly resolution. Artificial intelligence software will also aid nonroutine operations and anomaly resolution.

Breakthroughs in artificial intelligence software combined with vast databases of information will help model the knowledge required to fulfill the nonintervention requirement. Improvements in knowledge representation, along with vast amounts of encoded knowledge, will make these capabilities possible.

The world of computer science has continually progressed towards larger databases. The primary technical constraint is storage media capacity. Capacity is growing at an exponential rate and is continuing to grow—more and more data can fit in the same space. In the 1980s, magnetic storage media was common. In the 1990s, light-based storage using CD-ROMs is the trend in some terrestrial computers. The DOD is testing space-qualified optical disks on the STEP M3 (space test experiments platform) satellite and on STP-1 (space test payload 1) aboard the space shuttle.[48] In the future,

budding optical technologies such as holographic data storage systems may provide even greater storage capacity[49] in both terrestrial and space-based C^4 systems.

Knowledge representation has vexed computer scientists for years and continues to be a major constraint to fielding operational artificial intelligence systems. However, new schemas for knowledge representation are continuing to grow in strength. Formal computer methods such as "Z" improve the ability to model reality.[50] Trainable computer neural networks offer new methods of gathering and storing knowledge. Optical computers, combined with neural network technology (fig. 3-3), promise to provide extremely fast knowledge-base searches by exploiting the vast numbers of parallel interconnections that an optical computer could support.[51]

To enhance portability, antennas for contacting the satellite will be tiny. This will allow ease of transportation, rapid setup, and increased concealment in a hostile environment. To further enhance autonomous operations, antennas should not rely on off-site orbital analysts (engineers) to provide satellite location data for antenna pointing. The portable ground station will maintain its own information for pointing to the satellite.

Antenna size is a function of the wavelength of the signal, antenna gain, and aperture efficiency (fig. 3-4).[52] Advances in several engineering disciplines will combine to make antennas smaller. The antenna size required to transmit to a satellite will decrease with higher frequencies and smaller wavelengths. Advances in signal processing electronics will permit lower gain requirements, also decreasing antenna size. Finally, as new antennas are designed, relative antenna efficiency will increase.

The system must be seamless and transparent to the end-users to allow them to concentrate on the mission. User interfaces must be intuitive, requiring a minimum of operator training to cut costs and implementation times.

User interfaces for C^2 of satellite systems are constantly improving. In the early 1980s, the Air Force fielded the satellite C^2 software system based entirely on mainframe technology using character displays. The Air Force upgraded it in the late 1980s to more advanced mainframe

Laser Communication Optical Computers

Major Advantages:

- High data throughput
- Protection from EMP
- Exploits interconnectivity of neural networks

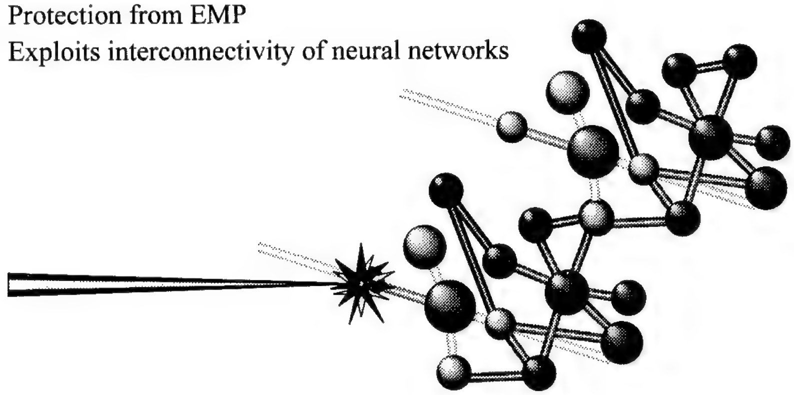


Photo from Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corporation.

Figure 3-3. Combining Laser Communication and Optical Computers

$$\text{Antenna area} = G\lambda^2/4\eta\pi$$

G = Antenna gain
λ = Wavelength
η = Aperture efficiency

Source: Timothy Pratt and Charles W. Bostian, *Satellite Communications* (New York: Jon Wiley & Sons, 1986), 81.

Figure 3-4. Calculation for Area of an Antenna

technology, but it still used character displays. The Air Force intends to move to a graphic computer interface in 2000 with the introduction of the Common Telemetry Tracking and Commanding System (CTT&C).[53] To control large constellations of satellites in 2025, it will be beneficial to have a 3D display of satellite locations, orbits, and the targets for mission packages.

Commercial companies built primitive, yet realistic 3D computer displays in 1995. GTE Corporation advertised the Collaborative Three Dimensional System (C-3D) for teleconferencing. An article in *Signal* magazine stated the system makes people "at distant locations appear to be in the same room, seated at the end of the conference table. When a ball was tossed by one of the distant users, it seemed so realistic that the editor involved reached to catch it."[54]

More advanced 3D displays are in research and development. Autostereoscopic displays require no viewing aids such as 3D glasses or head-mounted displays. Autostereoscopic displays offer the possibility of operationalizing 3D displays in future scenarios, since no more equipment is required beyond a display monitor. Texas Instruments is working on 3D autostereoscopic displays using "slice stacking" technology. In the same manner that a spinning line of lights looks like a plane, a rotating plane of lights appears as a 3D image. Texas Instruments is using vibrating micromechanical mirrors to produce this effect.[55] Massachusetts Institute of Technology has created holographic 3D computer displays in the laboratory.[56] The University of Washington's Human Interface Technology Laboratory is working on technology to paint a 3D image on a person's retina using microlaser technology.[57]

Given the growth in computer technology expected in the next 30 years, advanced 3D computer displays should be common by 2025. The commercial market will push the technology for these displays. Already, the entertainment industry is interested in the technology for telecomputer and interactive video games in the home.[58] The trend toward home use will help decrease 3D display costs.

Satellite Design

Satellite design directly affects the simplicity or complexity of on-orbit support requirements. Design philosophies for space systems in 2025 should simplify or minimize on-orbit support requirements and ensure the space system does not create debris problems on-orbit once it is defunct.

Design goals in 2025 may move toward distributed small microsatellite (microsat) systems, reusable microsat systems, or disposable microsat systems, as well as retaining some large, maximum longevity space systems.

Space systems should be almost entirely autonomous for both mission (payload) execution and C^2. The war fighter should have a pull system and get only the data needed, when needed, and in a format quickly assimilated. The war fighting environment of 2025 will be more complex for the battlefield commander, so the US must avoid the biggest risk to future combatants–information overload.[59] Today's

space operations mission control complex is staffed with several hundred operations and engineering support personnel. Space systems in 2025 must be able to "fly" with minimum human intervention.

Finally, proliferation of space systems in 2025 requires investigation of disposal issues—what to do with space systems when they no longer function.

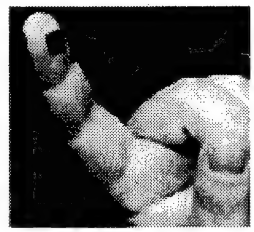
Microsatellites

Current space system design practices focus on maximum longevity to avoid costly replacement of the space system as well as associated launch costs. Redundancy of critical components or subsystems minimizes the chances of "single point failures." New smallsat designs for single- or dual-purpose satellites are several hundred pounds with a body the size of a three-foot cube. Advancements in electronics and miniaturization have sparked concept work on microsats—approximately shoebox-size and weighing between 20 and 30 pounds.[60]

The Micro-Devices Laboratory within NASA's Jet Propulsion Laboratory (JPL) has focused on developing miniaturized space instruments (figs. 3-5 and 3-6).

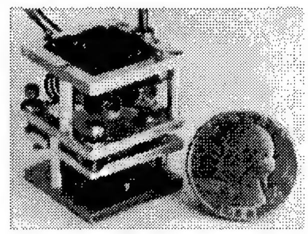
Engineers at JPL are also working on ways to reduce spacecraft to the size of a frisbee.[61] In early 1995, NASA launched its *New Millennium Program* at JPL. *New Millennium* envisions a twenty-first century program of affordable, frequently launched missions where numerous small and "micro" spacecraft will travel outward in armadas to study the earth, the solar system, and beyond.[62] Throughout the galaxy, these probes will feed information back to earth via telecommunication links to create a "virtual human presence" throughout the universe.[63]

At this time, the technology to produce microsats is not mature, mission capabilities are limited, and production is expensive. Within the next 30 years, miniature electronic components should be tested and demonstrated in space environments, driving microsat costs down



Source: NASA JPL, New Millennium Program Brochure, Internet Address: http://nmp.jpl.nasa.gov/About/Brochure/Graphics/page-2.gif.

Figure 3-5. Camera on a Chip



Source: NASA JPL, New Millennium Program Brochure, Internet Address: http://nmp.jpl.nasa.gov/About/Brochure/Graphics/page-2.gif.

Figure 3-6. Microseismometer

to thousands of dollars, compared to today's tens of millions of dollars or even much higher for many DOD satellites. With miniaturization, the new features of today's systems like cross-linking, autonomous operation, and reprogrammable onboard computers will help bring systems of microsats to reality. It should be feasible for a commander to order the immediate launch of microsats to cover a theater to perform communications, weather, surveillance, and reconnaissance missions.

Distributed systems of on-orbit microsats in 2025 could deliver seamless mission capabilities to the war fighters.

> True distributed satellite systems increase performance at a rate which is faster than linear with the number of systems deployed. For example, a single satellite can perform processing tasks for a large number of special purpose satellites if an on-board communication link is smaller or lighter than a dedicated processor. A central processor reduces the processing requirements of individual satellites in the constellation.[64]

Operators "in-theater" may be able to "task" the microsats' payloads to gather and deliver mission data directly to the war fighters. The more ambitious goal is total control of the microsats and their payloads in-theater (sufficiently behind the forward battle area), providing maximum responsiveness to the war fighters without the "armies of engineers" of today's systems.

Reusable Microsatellites

By 2025, an alternate power source for space systems may be possible, thereby eliminating the solar arrays and associated hardware. The satellites would be much "cleaner" on the exterior, making it possible to shield enough of the satellite from heat in order to facilitate reentry into the earth's atmosphere. This will make recovery possible and facilitate building and operating reusable satellites that can be launched for a tactical purpose. When the mission is complete, the satellite flies or parachutes to earth or is recovered by a transatmospheric vehicle and returned to earth for subsequent reuse.

Disposable Microsatellites

Very-low-cost and launch-on-need tactical microsats could be employed to support a theater commander for a limited amount of time—possibly only several months. These disposable microsats are exclusively owned and controlled by the theater commander. When the commander's mission is complete, the microsats are simply discarded.

Multimission, Maximum Longevity Satellites

Some large, multimission satellites with maximum longevity may still be necessary in 2025. The factors limiting space system longevity are electrical power, propulsion fuel, and radiation hardening of internal electronic components. Evolutionary improvements continue in each of these technologies. Any improvements will benefit both multimission, maximum longevity satellites and microsats.

Spacecraft Power. Current satellite components are electrically powered by solar cells or from storage devices like batteries when sunlight is blocked from the solar cells. Solar array size and efficiency, battery capacity, and the amount of power required by the satellites are the limiting factors. Today's silicon solar cells provide 11 to 12 percent efficiency, but development is underway on gallium arsenide cells with up to 20 percent efficiency.[65] Battery technology has moved from nickel-cadmium to nickel-hydrogen. According to *New World Vistas*, previously hard applications become easy and new applications become possible if power is not an issue.

Revolutionary improvement is required to make a leap to fully capable microsats in 2025. Possible revolutionary solutions are nuclear power,[66] laser power beaming, or electrodynamic tether systems.[67] Nuclear-powered satellites have been demonstrated, but political and environmental unpopularity have limited research and development. A laser power beaming system would employ a space- or ground-based high-power laser system to propagate a laser beam to a satellite's collection and conversion device. One possible system would use solar array-like devices to collect the laser beam and convert it to electrical power.[68] The Tethered Satellite System aboard space shuttle mission STS-75 was intended to demonstrate electrodynamic system technology using a 20.7-km-long tether to generate approximately 5,000 volts.[69] The tether broke while deploying the satellite—the capability remains untested.

Spacecraft Propulsion. Propulsion fuel is another limiting factor for space systems because it is used to maintain proper satellite orbit and to reposition the spacecraft for mission purposes. A propulsion system with minimal or no expendable fuels is the goal. Possible solutions are electric, nuclear, or laser propulsion, satellite refueling, or a space "tug."

Arcjets, plasma engines, and ion engines are three possible electric propulsion technologies.[70] These technologies could provide high energy with much less weight than current systems.

A nuclear propulsion system could, theoretically, more than double the specific impulse energy output of today's current liquid propulsion systems using a solid-core thermal reactor engine with liquid hydrogen propellant.[71] Once again however, research and development has been limited because nuclear propulsion systems are politically and environmentally unpopular.

A laser propulsion system may use a ground, airborne, or orbiting laser to transmit energy through an optical window on a spacecraft to heat a fluid—like a hydrogen/cesium mixture, for example.[72]

Another possible solution for spacecraft propulsion is on-orbit refueling via another satellite or transatmospheric vehicle.[73]

Figure 3-7 depicts another solution—moving the satellite with a space "tug."[74] The Tethered Satellite System aboard space shuttle mission STS-75 was also intended to demonstrate this space "Tug" concept.

Radiation-Hardened Electronics

Miniaturized electronic components contain more and more circuitry in smaller areas on silicon chips, making the chips more vulnerable to single event upsets, latchups, and degradation due to "total dose" (long-term exposure) radiation from the natural space environment or from nuclear counterspace threats.

The level of natural radiation a spacecraft endures depends on its orbit. Low earth orbit (LEO) systems encounter relatively little, geosynchronous (GEO) systems encounter somewhat more, and medium orbit systems like the NAVSTAR GPS satellites are exposed to significant radiation because they orbit at 10,900 miles—in the heart of the Van Allen radiation belts.

Radiation hardening of spacecraft electronics—particularly random access memory (RAM)—is a limiting technology for computing power in medium- to high-orbit systems today. Current preventive measures include shielding the electronics with tantalum, aluminum, or lead.[75] More elaborate silicon-on-sapphire semiconductor technology that is upset-resistant is in development.

There are only a handful of companies in the world that manufacture these "space-qualified" or "Class S" parts to meet DOD specifications because the business base is very small and the parts are very difficult and expensive to manufacture. Chips for these purposes do not double their speed and capacity each 18 months like chips for personal computers. The largest RAM chips flying in an Air Force satellite today are 16-kilobyte (K) chips in the MILSTAR spacecraft.[76] GPS Block II replenishment satellites will contain 64K chips. Some Hughes commercial communication satellites in high orbits today contain "commercial grade" 64K chips.[77] A commercial grade chip is not tested as rigorously and specifications are not as strict as for DOD Class S parts. Motorola's Iridium spacecraft (in a very low earth orbit) will reportedly attempt to use one-megabyte commercial RAM chips.[78]

Until recently, DOD and NASA missions drove the advancement of space electronic technology. The explosion of commercial space use now drives the state of the art. Two things must be considered, however.

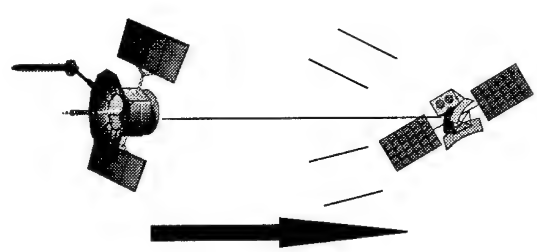


Photo from Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corporation. Photo from Federal Clip Art © 1995 with courtesy from One Mile Up, Inc.

Figure 3-7. Space "Tug"

First, some DOD space missions like GPS require medium orbits with high inherent radiation. Commercial ventures are unlikely to drive solutions as quickly for these missions. Second, commercial satellites are not designed to withstand radiation from hostile counterspace threats like ASAT weapons. Future DOD space systems must have a "countermeasure"—systems either designed to withstand the radiation threat or planned for satellite attrition and timely replenishment.

Space systems in 2025 must operate with minimal C^2 from much smaller operations crews. The *New World Vistas* team recommended automation to reduce the number of people involved in launch and mission control by at least a factor of ten.[79] Automation of some tasks like satellite thruster firings, attitude adjustments, and health and status monitoring can reduce operations crew size and minimize requirements for C^2. Autonomous operation designs will also allow 2025 space systems to continue seamless mission support to the war fighters if ground control capability is interrupted. The current NAVSTAR GPS Block II replenishment spacecraft requirement is to operate for 180 days without ground control while still maintaining mission requirements for navigation and timing accuracy. Cross-linking and GPS-augmented guidance should allow 2025 space systems to perform a preprogrammed mission independently for several years. NASA's JPL predicts that future satellites will have extraordinary navigational precision.

> Imagine a basketball shot from Washington, D.C., toward a hoop in Moscow, Russia—with the ball passing straight through the hoop, not even touching the rim. This accuracy is equivalent to NASA launching a basketball-sized satellite to rendezvous with a speeding comet.[80]

One key technology to enable ambitious automation and autonomy goals is onboard computing power. These autonomy goals require larger onboard volatile and nonvolatile memory to increase overall computing power.

Fiber optic or light-based computing technology could dramatically improve computing power for earth and space applications in 2025. Computers perform two basic functions: switching and communications. Optics do a good job with communication functions and are widely employed today for high-data-rate terrestrial communications. Switching functions however, generally require some material or device to facilitate photon-to-photon interaction.

> The switching function in today's electronic computers works because electrons are massive, charged particles that are easily manipulated with electric fields—thus the electronic transistor. The challenge of using optics for the computer switching function stems from the fact that photons are massless and chargeless so there is a difficult asymmetry in their properties and switching uses.[81]

Nonlinear optical materials may offer some possibilities.[82] One of the most promising approaches uses a device known as a self-electrooptical effect device (SEED).[83] The interim step to optical computing in 2025 is using optical preprocessing modules to operate in conjunction with existing electronic hardware—in effect, doing the communication portion of computing with optics and the switching portion with electronics. This interim approach can provide performance improvements over today's entirely electronic approach.[84]

Further, more simple and efficient software designs should employ commercial techniques to minimize costs and increase commonality with other space systems. *New World Vistas* recommended the Air Force drop the mandatory use of the ADA programming language and stop development of compilers and rely on commercial solutions.[85]

Space system reliability must be improved as well. Current space systems undergo significant factory and prelaunch testing to meet reliability requirements. They rely heavily on redundant systems to reduce risk of the most serious "single point" failures—that is, if a critical component is lost, the mission capability is

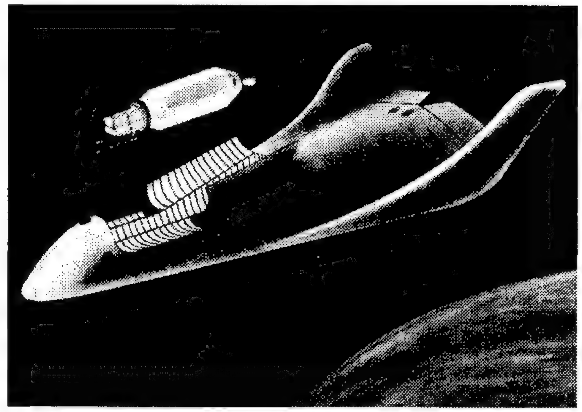
lost. Space systems in 2025 should employ more robust designs, maximum use of common and commercial components, and improved manufacturing methods to ensure the highest possible reliability from piece-parts up through the component and subsystem levels. Improved fault detection methods will also improve autonomy and automation. Onboard computers should be able to precisely trace most problems to the root cause and correct or compensate for them, ensuring minimum mission downtime and optimum system longevity. In 2025, electron "tagging" methods may be employed to determine precisely where errant commands came from or what caused a component to malfunction.[86]

Satellite Disposal

If space system disposal issues continue to languish, debris strikes will be a serious issue in 2025 and beyond. Space systems fielded in 2025 should have a disposal scheme inherent in the design. Depending on the orbiting altitude of the space system, several options are feasible. LEO satellites can be maneuvered or allowed to naturally reenter the earth's atmosphere and burn up—smaller space systems have little to no chance of any debris surviving reentry. GEO space systems can be sent away from earth by using a final allocation of fuel. Medium-orbit satellites like GPS orbit at 10,900 miles and present a greater challenge; propulsion fuel requirements to reenter the atmosphere and burn-in or jettison to outer space could be prohibitive without refueling or using a space "tug." Environmental concerns for outer space—or for "political correctness"—may prohibit the burn-in or jettison options.

A potential solution is a "spacecraft compactor" vehicle,[87] possibly a transatmospheric vehicle adaptation (fig. 3-8).

This remotely controlled spacecraft compactor could orbit the earth, maneuver, and retrieve defunct hardware or other "space junk." The compactor must contain hardware designed to avoid debris breaking loose, and it should compact the hardware to maximize onboard capacity. The contained, compacted blocks may then be jettisoned to outer space, burned into the earth's atmosphere, or returned to earth for subsequent recovery and disposal.



Source: Lockheed Martin Missiles and Space Corporation. Public Affairs Office, Internet, 5 April 1995. Available from http://www.lmsc.lockheed.com/newsbureau/photos/shuttle1.jpeg.

Figure 3-8. "Spacecraft Compactor"

Necessary for this capability are affordable spacelift to get the spacecraft compactor into space, a very strong, lightweight containing structure to hold the debris, and a propulsion system that is either refuelable or uses onboard "unexpendable" sources like nuclear power. Another concept would use an adapted transatmospheric vehicle.

Satellite Security

Successful military operations in 2025 will rely heavily on space-based systems to provide timely and accurate information on demand. These systems will enable planners, operational commanders, and personnel in the field to access critical information for making the "right" decisions. These right decisions will allow operations tempo control through a broad spectrum of operations from war to military operations other than war. Technologically advanced systems such as spacenet, GPS, MILSTAR, and other satellites allow the

exploitation of gathering and dissemination of information via space-based systems. Utilization of these spaced-based assets will drive new military doctrine designed to best exploit these capabilities. As reliance on these systems increases, it will become more important to protect them from hostile intent and to regenerate the system or the capability if satellites are destroyed.

Information collection and dissemination by space-based systems (satellites) will become a vital center of gravity and a high priority target for adversaries. US national security will depend on keeping the space lines of communication open. As the military continues to compensate for numerical superiority with technology, information collected by satellites will increase in importance. Hence, satellites are a vital force multiplier in the information age and beyond. Uninterrupted, timely, and accurate information is critical to the war fighter and planner of future campaigns and operations.

The US's commercial and military space-based systems' target value increases proportionally as the military's dependence on information from space increases. In the future, the military will rely increasingly on commercial systems to collect and disseminate information to aid in operational planning and execution. The proposed satellite defense systems utilize a variety of countermeasures to protect these vital space-based assets.

Defensive systems will be employed on all satellites to ensure that information on demand is not interrupted by incidental or intentional force. Since both commercial and military systems are vulnerable to a variety of threats, cooperation between these two sectors will be mutually beneficial in many ways. First, standardization will increase interoperability between systems. This will facilitate connectivity to and from information transfer media by establishing common coding, equipment, and procedures. Second, standardized designs will ensure that satellites fit onto launch vehicles without costly modification to the launch system or the satellite itself. Finally, standardized defense systems will ensure uninterrupted information flow which translates into profit for the commercial sector and security for the military sector. Defensive system funding for research and development and employment will be the responsibility of the military.

Limiting Factors

International law places many restrictions on the use of space-based weapon systems, whether intended for defensive or offensive purposes. There are two options to ensure that satellite defensive system designs are lawful. First, systems may operate within the intent of the existing laws by limiting the lethality of the weapons employed. For example, systems would not utilize weapons of mass destruction to negate a threat. Second, current laws, treaties, and agreements may be amended by the signatories to allow deployment of space-based weapon systems. The US must move cautiously, since other nations may use these amendments to deploy previously prohibited systems to counter the US advantage in space. Amendments should not promote the proliferation of weapons or ignite a space arms race.

Public opinion regarding nuclear-powered vehicles launched into space will have a significant impact on the type of security technologies employed. If capsules containing nuclear materials cannot be designed to maintain integrity in the event of catastrophic failure, significantly improved satellite propulsion and power systems will be extremely limited. Propulsion and electrical power systems are key to many satellite defensive capabilities.

Economics will determine the types and to what extent defensive systems will be employed. The assumption is that it is more cost-effective to employ small single- or dual-mission satellites than large multimission satellites. These large satellites with defensive system capabilities

are not cost-effective for a number of reasons. With launch costs approaching approximately $20,000 per kilogram,[88] they are far too heavy to be launched economically. Also, if one of the onboard systems fails or is destroyed, there are two options; replace the capability by launching an identical multimission satellite or do without the capability. The latter could have a catastrophic impact on military operations and readiness—it is simply unacceptable.

The principles of mass, economy of force, and simplicity are the foundation for a viable defensive strategy regardless of the medium—land, sea, air, or space. These principles can be exercised in deploying microsat constellations of single- or dual-purpose satellites, which could be launched at substantial savings. The redundancy provided by numerous constellations of single-purpose satellites would ensure no loss or degradation in capability if a single satellite is destroyed. Since readiness and operational capabilities would not be degraded or compromised, it would decrease the urgency to replace the satellite. The satellite will be replaced as soon as practical.

Cost-effectiveness will be further enhanced by the ability to build and deploy replacement systems quickly, economically, and en masse. Advances in miniaturization and development of durable materials will enable the production of small, lightweight satellites that are more economical to launch. Prompt replacement of obsolete or disabled satellites is vital to sustain defensive system capabilities.

Simplicity of design has at least three distinct advantages. First, fabrication and construction costs are kept at a minimum since cost per item is driven down by volume. Given budgetary constraints and swings in funding, it is not economically feasible to manufacture large, complicated, easy-to-detect systems that are vulnerable to destruction. The second advantage is speed of production. Simple, standardized systems require minimum production time. Plug-and-play technology already exists and is incorporated into many of today's satellites. As next-generation hardware becomes available, it is simply plugged into existing bays with no need for structural modifications. Third, simple can be made small. Miniaturization of components is practical only if they contain few moving parts and complex structures.

Roles and Missions

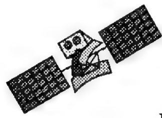
The objective of satellite security is to employ a space-based defensive system that is reliable, economically feasible, and timely to produce, maintain, and deploy in the quantities necessary to protect US space lines of communication. A successful security system ensures uninterrupted, timely, and accurate information from space.

Satellite security in 2025 will depend on a robust defense system with roles and missions having foundation in today's operational philosophies. Air Force Manual (AFM) 1-1, *Basic Aerospace Doctrine of the United States Air Force* was the primary source for establishing strategies for satellite security: specifically, the Principles of War;[89] Roles and Typical Missions of Aerospace Power,[90] and the Tenets of Aerospace Power.[91]

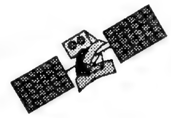
The defensive system supports several roles and missions (fig. 3-9). The counterspace mission will ensure the friendly use of space by employing interdiction to disable or destroy threats. The defensive systems will be supported by spacelift for launch and by on-orbit support for sustainment or replenishment.

Defensive Philosophy

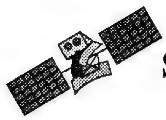
Given the vastness of space and the multitude of threats, no defensive system can be devised to make satellites invincible. The proposed satellite defense system will not counter 100 percent of all threats, but will reduce the system's vulnerability. It is more cost-effective and operationally feasible to replace damaged satellites than it is to expend limited budgetary funds in an



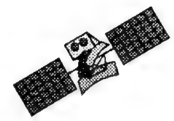
Supporting Roles & Missions



ROLES	MISSIONS
Space Control	Counterspace
Force Application	Interdiction



Supported Roles & Missions



ROLES	MISSIONS
Force Enhancement	Spacelift
Force Support	On-Orbit Support

Source: AFM 1-1, *Basic Aerospace Doctrine of the United States Air Force*, vol. 1, March 1992, 7. Photo from Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corporation.

Figure 3-9. Roles and Typical Missions of Aerospace Power

attempt to make them "invincible."[92] A multimission satellite with operational mission systems and equipment coupled with a vast array of offensive systems is economically impractical. "Single- or dual-purpose satellites must be the rule rather than the exception."[93] However, this does not preclude incorporating some defensive capabilities like shielding, detection, and maneuver into each satellite.

Space-based systems, by their nature, are protected against all but the most technologically advanced or economically "well-off" states capable of deploying or purchasing ASAT systems. To date, only Russia has pursued ASAT technology. However, it is prudent to assume that ASAT technology is available on the open market. As states or groups hostile to the US increase their treasuries through the sale of petroleum, arms, or advanced technologies, they will be in a position to purchase ASAT capability by the year 2025.

Strategies and systems described in this section are designed to counter man-made and environmental threats that interfere with the operation and transmission of data to and from satellites. Since their potential for destroying space-based systems is approximately equal, both threats were given equal weight when countermeasures were developed. Countermeasures were intentionally designed to overlap in order to provide redundancy and ensure effectiveness.

Since space debris and radiation are potential threats to all satellites, defensive systems should not exacerbate the problem. Countermeasures employed will not add to the amount of debris or radiation clouds already in space. Offensive weaponry will employ systems that eliminate debris from the environment and will not employ nuclear detonations with lingering radiation. To do this, the systems will totally vaporize the object or deflect it into a trajectory that will cause it to burn up in the atmosphere.

The ability to employ OODA loop logic will be a vital software capability. Software programs will perform threat analysis and will take appropriate countermeasures autonomously. This capability will rely on "artificial life"[94] software programs that react to a dynamic environment with the

appropriate force or action. This defensive capability will be incorporated into all satellites regardless of intended purpose. Satellites will use their unique capabilities to negate the threat and reduce satellite vulnerability.

Once a threat is detected, OODA loop logic will direct passive and/or active defense mechanisms on board the satellite to counter the threat. The appropriate countermeasures may be maneuver, activation of shields, or manipulation of satellite exterior surfaces. On ASAT platforms, offensive countermeasures such as activation of directed energy (DE) or kinetic energy weapons will be initiated by artificial life software programs. Passive identification friend-or-foe systems (encrypted) will hasten detection of friendly satellites.

Survivability will be enhanced by designing energy-absorbent materials into the exterior surfaces of the satellites. These materials will serve two purposes: (1) defense and (2) power regeneration. Energy (solar, laser, radar) will be absorbed by the external materials and converted into energy to power the satellite's operating defensive systems. If not needed immediately, the energy would be stored in batteries for later use.

Threats

Satellites face two potential threats in space: (1) environmental (meteors, asteroids) and (2) man-made (space debris, offensive weapons). Approximately 2 million kg of man-made material orbits within 2,000 km of earth.[95] Add to this another 200 kg of meteoroid mass the same distance from earth and the probability of damage from impact is high.[96]

Environmental Threat. Environmental threats include solid debris resulting from the disintegration or decomposition of celestial or man-made materials. Countermeasures will have to nullify the effect of kinetic energy expended from particles traversing space and impacting the satellite. Projectiles traveling through space reach ultrahigh velocities, making even the smallest particle a potential threat to satellites. Tiny particles act like sandpaper eroding external surfaces whereas larger particles are capable of totally destroying a satellite.

Radiation from any source—environmental or man-made—also poses a significant threat. Unlike kinetic energy damage, the effects of radiation are not always instantaneous. Like corrosion, radiation decomposes material in space, erodes surfaces, and undermines the integrity of the structures. The insidious nature of this erosion makes degradation difficult to detect until the damage is severe.

Man-Made Threats. This category includes deliberate actions taken against a space-based system for the purpose of disabling or degrading the satellite. Typically, these threats are designed to destroy or disable instantaneously. Their targets will have to be replaced. DE weapons are one example of a man-made threat employed to inflict an instantaneous effect or an insidious effect. Regardless of the speed with which they act, these threats must be countered. Any loss or delay in information transfer to the end-user will impose serious consequences on operational capabilities.

Countermeasures

To ensure optimum effectiveness, defensive strategies will be developed to exploit the synergistic effect of passive and active defense mechanisms. Most satellites will employ predominantly passive systems with the exception of the ability to maneuver—an active measure. Utilization of these strategies will facilitate simplicity of design and allow for a smaller physical cross-section, which in itself provides a defense mechanism. Passive defense can provide great benefits due to the amount of energy saved from not having to maneuver or activate offensive systems.

Using the single-purpose design philosophy, offensive strategies will be executed only by hunter killer (HK) and decoy satellites. These HKs are designed to

employ offensive systems and their only function is constellation defense. Decoy satellites which morph the physical attributes of other satellites will be deployed to add a degree of deception to the overall defensive system.

Passive Defense. This concept relies on three strategies for all satellites: low detectability, shielding, and ultrahigh orbits. These strategies are incorporated into the structural design of the satellite and are primarily defensive in nature—they require no energy expenditure from the satellite itself. The strategy is to reduce vulnerability, not eliminate the threat.

Low Detectability. Visibility equals death. Low satellite detectability may be achieved via three technologies: (1) energy absorbent materials, (2) nonreflective surface design (also referred to as energy diffusion design), and (3) energy refracting and/or reflecting material. Each technology is designed to defeat a specific detection medium (acoustic, energy, or optic sensor). These materials will double as a component of the satellite's energy conversion system, which will convert hostile energy into a potential satellite power source.

Shielding. This strategy will provide some defense against kinetic energy and radiation threats. Defense against kinetic energy threats will take the form of "reactive armor" designed to absorb and dissipate the inertia of projectiles traveling at ultrahigh velocities. Behind the reactive armor, the satellite's external structures and surfaces will be set at acute angles to deflect projectiles should they penetrate the reactive armor. Because of the ultrahigh velocity of objects traversing space, it is impractical to defend against all kinetic energy threats. Total protection would make satellites too cumbersome and expensive.

Ultrahigh Orbits. These orbits enhance defense and operational capability. Defense is enhanced, since satellites are simply out of reach of most ASAT systems. If an ASAT system is employed, it will have to travel great distances to maneuver into an offensive position. While the ASAT travels this extra distance, the satellite may activate defensive countermeasures or move out of the threat area. These orbits enhance operational capabilities by providing a better vantage point for some information collection.

Active Defense. This strategy will employ distributed satellite systems, detection, maneuver, deception, decoys, and HK satellites. In keeping with the single-purpose philosophy, only decoy and HK satellites will possess an offensive capability.

Distributed Satellites.[97] This strategy uses several constellations of single-purpose satellites. Each constellation will work together to provide operational support and defense from specialized systems. Constellations will be deployed in a defensive formation similar to that used by the Navy's carrier battle groups. Each constellation is comprised of several mission satellites surrounded by HK and decoy satellites to provide fire support to counter threats (fig. 3-10).

Numerous constellations provide redundant capabilities and make it impossible for an adversary to totally incapacitate a specific capability. This redundancy will ensure continuous information transmission if one constellation is permanently or temporarily disabled.

Detection. Mission, decoy, and HK satellites will posses detection capabilities to identify hostile threats in space or on the ground. Space-based threats will be identified as friend or foe through use of transponders fitted to all friendly commercial and military satellites. Ground threats, identified after initiation of hostile action, will be targeted and destroyed or temporarily incapacitated by onboard systems. Detection systems would utilize laser radar (LIDAR)[98] to detect changes in atmospheric conditions or IR sensors to detect heat signatures from hostile platforms. Once a hostile threat is detected, each satellite takes the appropriate action based on capabilities. For example,

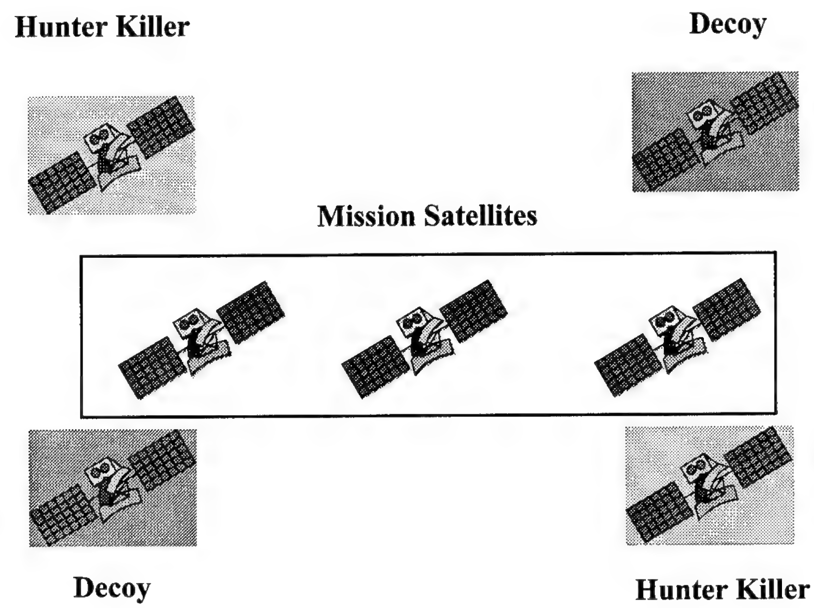


Photo from Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corporation.

Figure 3-10. Typical Satellite Constellation

mission satellites maneuver, decoy and HK satellites take offensive action.

Maneuver. This strategy includes nonstandard or irregular elliptical orbits. Maneuvers will be programmed into the artificial life software options available in the OODA loop process. Nonstandard orbits will make the targeting equation more difficult by eliminating satellite orbit predictability. Satellites will possess limited capability to maneuver over vast distances. Added weight and size of propulsion systems increase the cost of production and launch.

Deception. All satellites will be designed to look similar, regardless of function. Solar panels provide electricity on mission satellites and will also function as threat detection antennas on decoy and HK satellites. It will be difficult for sensors to detect the differences in satellite function, thus complicating an adversary's targeting problem. To eliminate or impede a capability, it will be necessary to target the entire constellation. This will be time-consuming and may require more assets than the adversary is willing to expend.

Another idea for deception is to design satellites that look like asteroids or space debris. Synthetic surfaces could be designed to act as functioning surfaces for the collection or transmission of data.

A projected virtual image (VI) capability can be incorporated into decoy and HK satellites. This system will project a holographic image into space to deceive optical sensors. Once a hostile weapons platform takes action, the VI projecting satellite will target and destroy it with one of its weapons.

Decoy Satellites. Decoys will look similar to mission satellites, but instead will possess the ability to maneuver and impact (ram) hostile platforms. They will be fitted with detection and propulsion systems to facilitate their mission.

HK Satellites. HKs will be the fighter escort of the satellite system. They will be deployed specifically as an offensive weapon

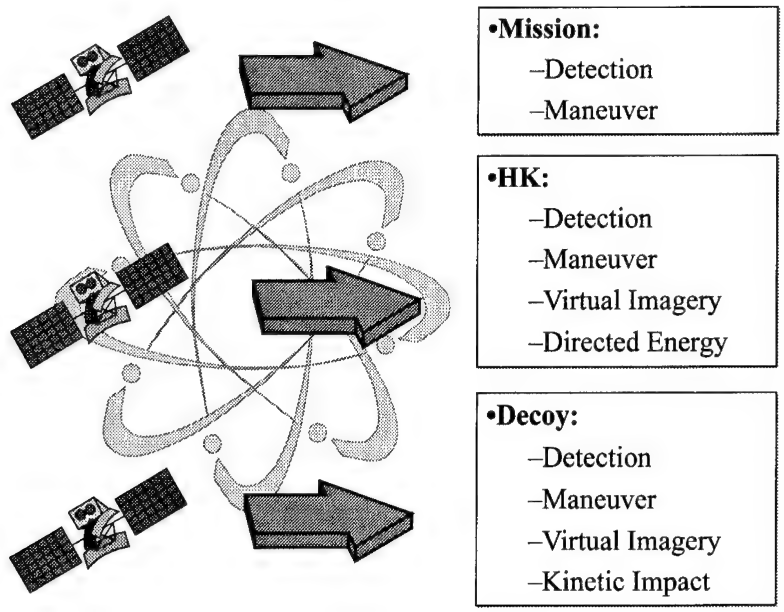


Photo from Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corporation.

Figure 3-11. Typical Satellite Defensive Capabilities

platform employing DE weapons (these include speed-of-light weapons, high-power microwaves, and laser). These satellites will identify hostile platforms (in space or on the ground) and destroy or disable them.

Figure 3-11 shows each type of satellite in a constellation—and its capabilities. Each satellite in the constellation provides functions so the "whole" spacenet constellation is more capable and secure than the sum of the parts. The spacenet satellite security system will ensure that uninterrupted, timely, and accurate information is delivered to the war fighter without fail.

Summary

The four pillars of the Spacenet 2025 system are support to the war fighter, C^3, satellite design, and satellite security. Each pillar contributes synergistically to the spacenet system capabilities. The spacenet system ensures that the US maintains space dominance well into the next century. The next chapter will outline the spacenet concept of operations and show how each pillar fits into the system. A notional scenario will show some of the routine spacenet uses and capabilities in 2025 and beyond.

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Chapter 4

Concept of Operations

As a potential crisis is identified, a theater commander requests space support for an area of responsibility (AOR). Space support in 2025 will include a few large, national, multimission platforms that collect information from the AOR and distribute processed data through centralized channels. Priority and control of these national assets remains with the National Command Authorities (NCA).

The majority of space support comes from large numbers of microsats in distributed constellations. Some microsat systems continuously orbit the earth as part of established space support. Existing systems provide immediate force enhancement and force multiplier support, but do not adequately provide the "eyes and ears" for the theater commander in 2025. However, more constellations of reusable and disposable microsats are launched within four hours of the execute order. These systems provide tailored, optimized support to the commander and forces. These assets and the operators are "owned" by the theater commander and are fully responsive to the needs of the forces in the AOR. Constellations are a robust mix of single- and dual-purpose satellites performing communication, navigation, weather, reconnaissance, and defensive missions.

The combat satellite operators near the AOR will deploy from their garrison to remote locations. Once in place, they will command satellites into position to facilitate force support in an impending deployment or conflict. Satellite operators easily carry their equipment with them on the deployment and require almost no additional logistics infrastructure to move their equipment—in some cases, it is stuffed in a side pocket of their rucksack. This portability is a result of extraordinary miniaturization of electronics and the ability to process and distribute force enhancement data from space in 2025.

Upon reaching their locations, the satellite operators immediately set up small C^2 systems, gain control of assigned satellites, and begin employment activities necessary to meet the information needs of the theater commander. Coordination with orbital analysts is not necessary since each small ground-control station immediately and automatically tracks the correct satellite. Anomalous conditions on the satellite are brought to the attention of the operator along with a list of recommended options to fix the anomaly—the operators do not need to refer to any engineers to solve most problems.

Satellite operators are difficult for the adversary to detect because their transmitters emit very narrow directional signals. In addition, the adversary has difficulty searching for the satellite operators, since they are not required to be anywhere near the AOR or the commanded satellite. If the enemy should get lucky and detect one of the satellite operators, the operator immediately grabs the portable equipment and moves to another location. If the operator is neutralized there is no emergency—the satellite continues its mission autonomously until another fully trained and capable operator takes over.

Operators control some microsats dedicated to the theater or military operation—control is not shared with other users and satellites may be reconfigured or maneuvered to support the theater commander. However, other operators are responsible for transmitting mission requirements for national multimission assets to the respective control center to satisfy the theater commander's requests.

The commander gets immediate feedback when support will be delivered.

Operators anywhere on earth or in space directly uplink signals to spacenet and the signals are routed between orbiting assets to the intended satellite. Spacenet is a seamless, "invisible" system because it operates with reliability and efficiency that even terrestrial utility companies try to emulate in 2025. Extraordinary amounts of data are exchanged nearly instantaneously through laser cross-links between space systems.

The commander's forces in the AOR easily "pull" the data they need from the space systems. Artificial intelligence and "smart" software ensure that the tank drivers, infantry, sailors, pilots, and commanders in 2025 get the data they need—without the reams of accompanying "chaff." Enemy forces have access to much of the same information through commercial means, but the US OODA loop is tighter, enabling reactions well inside enemy capabilities and maintaining military superiority.

The satellites themselves are a mixture of technological masterpieces (a few national, multimission systems) and many small, cost-effective, and reusable or disposable microsat systems. These small, cost-effective, 30-pound spacecraft of 2025 parallel the unexciting but highly efficient six-dollar pocket calculators of the 1990s. The space systems of 2025 do not suffer from limits of electrical power and propulsion fuel like space systems of the 1990s—nuclear power and electric propulsion eliminated such limitations. Further, optical computers on board the spacecraft are highly resistant to radiation and provide colossal computing power and data throughput. This computing power enables maximum satellite autonomy. Preprogrammed missions require no human intervention from start to finish unless changes are required. "Standardized" changes are commanded using macros—and more elaborate one-of-a-kind changes take a few more keystrokes from the operator.

In 2025, "space-capable" adversaries cannot negate US space forces. Microsat constellations provide inherent defensive capabilities. A constellation may include several operational, single mission microsats, two HKs and two decoy microsats. Both passive and active defenses are employed through low detectability, shielding, autonomy, detection, maneuver, deception, and HK offensive systems. When an adversary takes out a few US microsats, an execute order is issued for a four-hour response launch for replenishment microsats.

At the end of the conflict the large, multimission satellites continue their mission of global awareness and global presence. The distributed microsat systems continue normal operations. The cost-effective, single mission reusable satellites launched specifically for this operation are de-orbited to their recovery base in the Mojave Desert where they will be refurbished and prepared for the next operation.

Satellites reaching the end of their service life, particularly the "disposables," are later collected by an orbiting "spacecraft compactor." This transatmospheric vehicle (adapted to a cleanup mission) collects defunct hardware, compacts it into small, dense cubes, and jettisons them deep into space.

Chapter 5

Investigation Recommendations

The effectiveness of the Spacenet 2025 system is best examined by "grading" it against measures of merit relevant to the alternate futures of 2025. The Spacenet 2025 system is highly effective, according to the measures of merit. Next, the paths to achieve the key technologies of the system are outlined. These require an *evolution* of space systems and related technologies with some technological *revolutions* as springboards to evolution at the system level. The spacenet system is achievable within 30 years.

Measures of Merit

Examination of measures of merit for the Spacenet 2025 system proves its military value in the alternate future worlds. Starting with the three tenets of Air and Space Superiority—awareness, reach, and power—the AFIT operational analysis team and the ***2025*** white paper teams derived over 100 force qualities and associated measures of merit to evaluate the ***2025*** white paper concepts. When the spacenet 2025 system was analyzed against all force qualities, the results showed 29 measures of merit from nine categories as valid measurements for this system:

1. Ground Survival
2. Identify
3. Integrate
4. Monitor
5. Plan
6. Decide
7. Communicate
8. Space Survival
9. Maintenance in Space

Ground Survival

First, the ground survival category measures performance of the ground portion of the Spacenet 2025 system—specifically the small, portable C^3 devices used to operate the satellites.

Detection. Spacenet 2025 will use small, mobile communications devices in the field to communicate through spacenet for C^2 of spacenet satellites. The mobile terminals should be as small as today's handheld cellular phones. Focused beam EHF signals minimize the probability of signal intercept. Large frequency ranges available in the EHF band allow spread spectrum communications to make signals blend in with everyday radio-frequency background noise. Packaged switched technology enables burst communications—minimizing the time of radio transmissions, reducing the probability of detection.

Countermeasures. EHF communications can use very small antennas, possibly only inches in diameter. Miniaturization of electronics should yield handheld space communication devices by 2025. These communications devices allow instant mobility, minimizing the probability that the user will be hit by an adversary if detected.

System of Systems. Spacenet accommodates many simultaneous users, giving "spatial distribution" so it is impossible to hit all system users. The war fighter in the field has multiple paths to transmit or receive information, since transceivers can be distributed anywhere in theater or the world. Loss of as many as 10 percent of the satellite C^2 nodes should not impact the spacenet system since multiple nodes can be spatially distributed anywhere on the earth. Further, the small, portable communication devices are relatively inexpensive and easily replaced. If some field devices are neutralized, replacements are easily deployed.

Identify

The identify category measures spacenet's ability to accurately recognize situations of interest to the war fighters, including possible natural or man-made threats against spacenet.

Tempo. Spacenet 2025 provides global coverage for the war fighter. With "eyes and ears" and efficient data processing in space, war fighters receive critical information from spacenet on demand. Spacenet 2025 provides the earliest possible sensing, detection, and data delivery to maximize war fighters' operations tempo. Indications and warnings delivered by the spacenet system allow the war fighter to anticipate some enemy actions in advance. Further, spacenet can detect, identify, and engage hostile ASAT systems before they can attack.

Traceability. Spacenet uses package-switched digital technology to transfer information between satellites and users. Package-switched technology provides an address of both the intended recipient and the original sender with each package that flows through the spacenet system. These addresses give users the ability to trace all information through the spacenet system.

Accuracy. Spacenet systems will be highly accurate. Increased multispectral sensing capabilities and onboard computing power will enable spacenet to correlate data with great certainty. This correlated data could be force enhancement data for war fighters or information about hostile threats to the spacenet system itself. Spacenet will use onboard databases and intelligent software to compare real-time data with stored threat information to maximize accuracy of processed information.

Resolution. Technological advances in multispectral sensing will improve resolution to levels not possible today. Miniaturized, distributed spacenet systems in low earth orbit can collect multiple data sets and synthetically combine them to improve resolution and fidelity. An example is multiple missile warning systems detecting an event, exchanging information through cross-links, and computing the solution for improved geolocation. These same sensor and computing advances will also provide enhanced resolution in identifying counterspace threats.

Integrate

Next, the integrate category measures spacenet's ability to integrate data into a coherent picture to support the war fighter and help negate threats against the spacenet.

Battle-Space View. Co-orbiting spacenet systems will provide excellent overview of any battle-space area on or near the earth. Large numbers of microsatellites in LEO can provide continuous coverage of an AOR. When proximity to the AOR is not critical, a few satellites in geosynchronous orbit can "see" the entire earth and space theater out to 22,000 miles. Spacenet is designed to be modular, and is easily expanded to cover different AORs as priorities change.

Tempo. Spacenet 2025 provides global coverage for the war fighter. With significant data processing using intelligent onboard software, spacenet will rapidly integrate data in the least possible time and transmit it to the users on demand. With unparalleled coverage of the earth from space, the spacenet system integrates and provides critical data to war fighters in advance of hostile enemy actions, maximizing the operations tempo.

Correlation. Using onboard databases and knowledge modeling, spacenet satellites and their accompanying defensive satellites will have access to historical information about missions, targets, and threats. Spacenet will make maximum use of historical data to correlate and process "raw" or real-time data and communicate the conclusions to the war fighters that need the data. The onboard computers "know" who needs particular data, and they filter information to avoid overload.

Monitor

The monitor category measures the ability of the spacenet system "owners" to track and control spacenet resources.

Resources. The spacenet is a self-monitoring system. Spacenet communication nodes keep track of other nodes and terrestrial users to route communications traffic via the most efficient means, routing traffic around degraded or destroyed nodes. Further, the spacenet system can provide health and status data of any satellite in the system to the appropriate ground controllers worldwide. The spacenet system ensures the theater commander and individual ground controllers know the status of all theater space resources. The spacenet system does its own battle damage assessment. If a spacenet satellite or ground terminal is "alive," the users will know it; appropriate operators are immediately notified if an asset is "killed."

Forces. Spacenet can track satellite controllers on the ground by locating controllers when they contact the spacenet. Protocols can "poll" the spacenet to ensure that in-theater controllers "check in" at selected times. Thus, we know that they are still alive and controlling their space assets. If a controller has not checked in, a replacement controller deploys immediately.

Plan

Next, the plan category measures how spacenet prepares for upcoming situations.

Effective. The goal of spacenet is to provide timely, global, and secure communication of force enhancement data to war fighters on the earth, in the air, or in space. War fighters identify the targets and use the spacenet system to get the information needed about the targets. Spacenet system priorities will be set at the appropriate levels. Theater commanders set priorities for spacenet assets they "own" (like the tactical, disposable microsats). National authorities establish priorities between theaters for shared spacenet systems. The "Internet in space" feature of the spacenet system ensures instant connectivity and maximum flexibility to change goals, targets, or priorities.

Efficient. The spacenet system is efficient in many aspects, ensuring reduced operations costs and minimum logistics support. Common spacecraft components ensure maximum connectivity at the lowest cost. People, aircraft, unmanned aerial vehicles, or other satellites can use small lightweight communications devices for standardized communication with the spacenet and other systems that communicate with the spacenet. Nuclear systems, laser power beaming, or electrodynamic tether systems may provide cost-effective, efficient power for spacenet satellites. Nuclear or electric propulsion systems provide a nearly unexpendable energy source to maneuver spacenet satellites. Inexpensive, disposable microsats may provide optimum support for short, tactical missions.

Decide

The decide category measures spacenet's capability to use information to make a decision and the overall quality of the decision made.

Decision Basis. The spacenet system uses optical devices to store the information needed by onboard computer systems for decisions. Optical systems will store orders of magnitude more data than today's electronic systems, providing a solid foundation for the decision-making software. Optical storage could come in the form of holographic data storage. Knowledge for decisions could be represented in advanced formal data models such as "Z."

Quality. To avoid information overload, it is important for the spacenet to make high-quality decisions about traffic routing, data delivery to users, spacenet defense, and autonomous operations. Artificial intelligence will help ensure high-quality decisions. Genetic algorithms can adapt themselves to changing situations to improve their actions. Neural networks

perform pattern-matching to choose optimal courses of action for a given situation. Highly capable computers on board spacenet satellites enable complex calculations to ensure the highest quality decisions.

Communicate

The communicate category measures spacenet's communication abilities.

Capacity. Spacenet is partly a communications system. Spacenet provides communication capacity to terrestrial, aerial, and space-based users. Those users could be people, autonomous sensors, or unmanned vehicles. System capacity depends on the communications medium in 2025, and on data compression improvements. Spacenet will transfer data at 400 gigabits per second for a single visible light laser (expected not later than 2010). If technology moves beyond visible light lasers by 2025, data transfer rates could exceed 15 terabits per second for ultraviolet lasers, or 1,000 terabits per second for soft X-ray lasers. Each of these data throughput rates may improve from 20 to 50 times, through use of advanced data compression schemes such as fractal compression.

Connectivity and Interoperability. The spacenet digital communications scheme will connect to many standard systems. Spacenet must connect to many systems since it will use both civilian and military space-based communication nodes. Spacenet also provides connectivity to users without direct spacenet transceivers through terrestrial Internet compatibility.

Security. Spacenet will ensure that unauthorized users cannot tamper with its internal configuration. Improved data encryption units and authorization codes will protect vital information. This security also prevents tampering with onboard packet routing information, prioritization, and defensive tracking and targeting information. Spacenet must also protect "friendly" communications and data from unauthorized users. Small encryption units on authorized military spacenet transceivers provide this security. Cryptographic key codes will change regularly to deny enemy use of "captured" spacenet transceivers. Encryption protects satellite cross-links, uplinks, and downlinks. Laser cross-links take advantage of laser pinpoint accuracy to minimize probability of signal intercept. EHF uplinks and downlinks provide narrow footprints on the earth, making it more difficult to intercept signals. Spread-spectrum, short-burst transmissions also make spacenet uplinks and downlinks difficult for unauthorized receivers to detect and record.

Data Accuracy. The communications channel provided by spacenet should follow commercial standards for data accuracy. Advanced error correction encoding or error detection and retransmission technology ensures data accuracy.

User Friendliness and Human Interaction. The Spacenet 2025 system will use 3D computer displays to ease the human-computer interaction.

Space Survival

The space survival category measures spacenet's survivability in the harsh space environment.

System of Systems. Spacenet consists of many different orbiting communications, mission, and defensive satellites. The distributed design of the system ensures that the spacenet will still be able to accomplish the mission and route communications traffic to other nodes if some of the satellites fail. Ultimately, the user will nearly always get the data desired.

Countermeasures. The satellite security section defines active and passive countermeasures available in spacenet to counter threats to individual satellites and the system as a whole. The system is able to counter both natural and man-made kinetic and radiation threats.

Detectable. The satellite security section defines three possible low-detectability technologies incorporated into military spacenet satellites: energy diffusion surfaces,

energy-absorbent materials, and energy-refracting or -reflecting materials. Each technology defeats a specific detection medium. To keep costs low, civilian spacenet satellites will not use low-detectable materials.

Vulnerability. Spacenet is primarily many small, distributed microsatellites, each providing an independent mission, communications, or defensive function. A weapon or a natural object impact could destroy these satellites because they are small. The relatively low cost and easy replacement of spacenet microsatellites offsets this vulnerability.

Maintenance

Finally, maintenance in space measures the maintenance aspects of the spacenet system.

Maintenance Footprint. Spacenet has no need for separate system maintenance in space. Spacecraft are self-maintained by well-designed systems. These systems use intelligent materials and some micro-miniature machines for small-scale subsystem repair. If an entire satellite fails, the spacenet system knows to bypass it until a replacement satellite arrives. When they break, the relatively inexpensive micro-satellites are "thrown away" and replaced. "Unexpendable" propulsion sources minimize any refueling or space "tug" requirements. The spacenet 2025 maintenance footprint should approach zero.

Reliability. Spacenet satellites will have a high mission capability rate from simplicity and the ongoing self-maintenance scheme of each subsystem provided by microminiature machines and intelligent materials. Onboard computers and autonomy ensure maximum mission availability. Satellite designs in 2025 minimize satellite failures caused by the harsh space environment.

Security. To avoid tampering with the internal system functions of spacenet, security measures and procedures protect each spacenet satellite from the time it leaves the factory until launch. Once on orbit, active and passive security systems ensure continuous protection against enemy threats—both physical and signal-intercept threats.

Storage Volume. Spacenet microsatellites are small and made of common parts. The common parts make the satellites quick to assemble. This avoids the need to have a large number of spacenet satellites built and awaiting launch. Should a spacenet satellite fail, a replacement will be assembled in a few hours from the common parts and launched into orbit the same day. Since the satellites are small, they will not take up much room if stored, nor will they occupy significant space in the launch vehicle payload fairing.

Time Lines for Development

Future time lines described in this section were developed using the Horizon mission methodology. The Horizon mission methodology starts with a given end state, then describes those changes that must occur to achieve the end state. The methodology works back from the future to the present, until it describes the current generation of technologies.

Improved war fighter support begins with today's initiatives, like Technical Exploitation of National Capabilities (TENCAP), to connect the "sensor to the shooter." Evolution of these systems, combined with some revolutionary improvements in information processing and storage and intelligent software for use on earth and in space, will lead to a highly efficient user-pulled system in 2025. The key to success is to ensure a continuous partnership between the users and the war fighters in the development process from requirement identification to demonstration, validation, and production.

Improved C^3 for the Spacenet 2025 system also requires a stepped approach. First is today's initiative to minimize on-site personnel at satellite remote tracking stations, resulting in unmanned, global, fixed satellite command and control. The next step requires miniaturization of

electronics and computing power to enable these same systems to become portable. High-rate, robust earth-to-space and space-to-space data transfer must evolve in parallel. Laser cross-links and other technologies co-developed by the commercial and military communities will make the spacenet a reality by 2025.

The road to microsat constellations in 2025 begins with today's miniaturization initiatives by DOD, commercial entities, and NASA's *New Millennium* program. There is probably one generation of "medium sized" 500–700-pound satellites between now and the 20- to 30-pound microsats of 2025. Revolutionary leaps in spacecraft power, propulsion, and computing power are required, along with evolutionary growth in autonomy capabilities, to implement the Spacenet 2025 system. Leadership by the commercial space world and integration of capabilities into military uses is also vital.

The world of 2025 may include several "space-capable" nation-states. To ensure that the US maintains space dominance, countermeasures must minimize the perceived natural and hostile threats to US space assets. A defensive strategy could include passive and active defensive measures and fast, cost-effective satellite replenishment.

The general progression to spacenet 2025 starts with today's "demonstration systems" like Clementine and TAOS, that are proving the concepts of autonomy, miniaturization, and simplicity. The US should aggressively lead a forum to share "lessons learned" between military, civil (NASA), and commercial space programs. Once proven, the "medium-sized" satellites will replace today's large, multimission platforms. These "medium" systems open the door for the Spacenet 2025 system of microsats that ensures US control of space throughout the twenty-first century.

Serving the War Fighter

The true measure of spacenet is its ability to get critical information to and from the war fighter in near real time. This information may come in human-readable form, or machine-readable form for controlling devices such as unmanned aerial vehicles or sensor systems. This real-time information capability will require the development, refinement, and integration of numerous systems with the spacenet (fig. 5-1).

Although portable satellite communications systems exist now, they will continue to become more transportable while providing more throughput. Connectivity will increase as more systems adopt standard

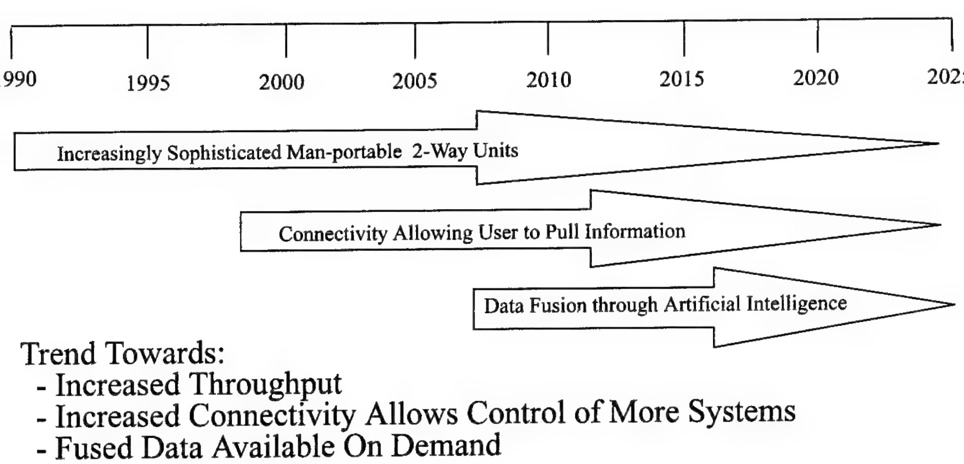

Figure 5-1. Advances in Fielded C^3 Systems

protocols for data transmission. This will occur as space communications become more commercialized. Finally, as the information explosion grows, consumers will demand improved methods to avoid drowning in a sea of data. Data-fusion technologies will grow, dependent upon increases in artificial intelligence.

Communication Systems Development

In 2025, high-speed cross-links between satellites will be used to interconnect mobile and remote forces (fig. 5-2). The move towards satellite cross-links, already started in 1996, needs to continue for satellites to provide communications capabilities needed in 2025. Moving towards higher frequencies will come naturally as the commercial satellite market provides more throughput.

Space-Qualified Computer Development

Several systems outlined earlier require advances in computer processing and storage. Commercial computer and satellite markets will push these advances. As the commercial satellite market grows, more-capable space-qualified computers will emerge (fig. 5-3). As communications technologies increase in speed, space-qualified systems will become faster, driving towards optical computing technology.

Common Subsystems Development

In 2025, satellites will use common subsystems, making them less expensive than those of 1996 (fig. 5-4). Common systems are just starting in the commercial space industry, with the Hughes standard satellite bus "series 600." Given a standardized bus, standardized subsystems such as power, propulsion, and attitude control are the next step. The final step is to make components from different manufacturers standardized in much the same manner as interchangeable personal computer components today.

Defensive Systems Development

Active and passive satellite defenses will increase the survivability of a satellite system in 2025 (fig. 5-5). As more and more civilian satellites are launched, civilians will protect their investments by making their satellites more survivable in the natural space environment. The military will need to pursue defenses against man-made attacks.

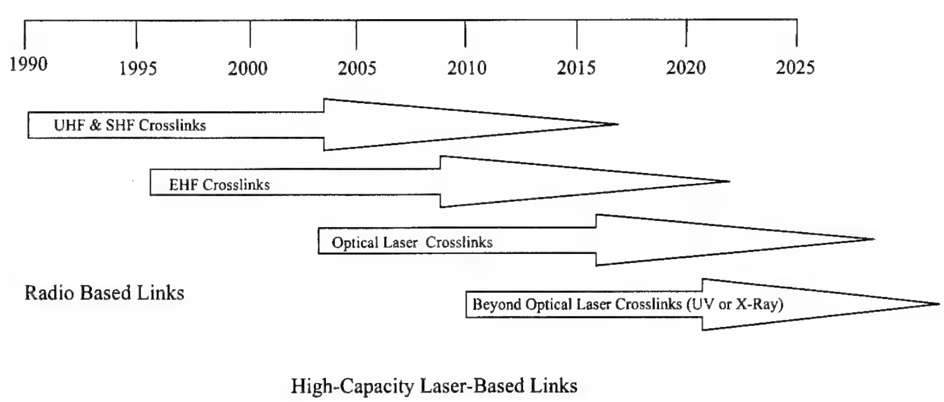

Figure 5-2. Technological Advances in Satellite Cross-Linking

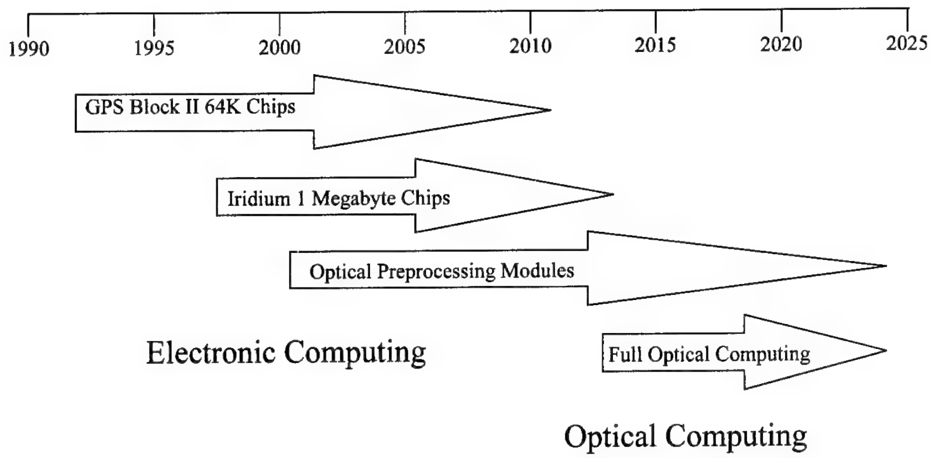

Figure 5-3. Advances in Satellite Computer Technology

Recommendations

Government and the commercial sector must leap forward harmoniously to maximize synergy and continue on course to achieve the common long-term goals: US economic prosperity and continued US space dominance throughout the next century.

Three categories of recommendations are worth consideration. First, the commercial sector should lead advancement in some technologies. These will be evolutionary and natural progressions, and they should directly enhance growth and profitability in the commercial sector.

Second, the Air Force/US government should provide incentives in some technology areas that are not necessarily in the commercial evolutionary path or that may involve high risks and DOD-unique requirements. The Air Force should fund technology programs in this category to reduce risk, and they should provide incentives to the commercial sector to "take over."

Finally, technologies that the Air Force/US government should lead are very broad-based activities requiring overarching leadership—at least to get started. The US government should lead the spacenet C^3 system architecture development just as it

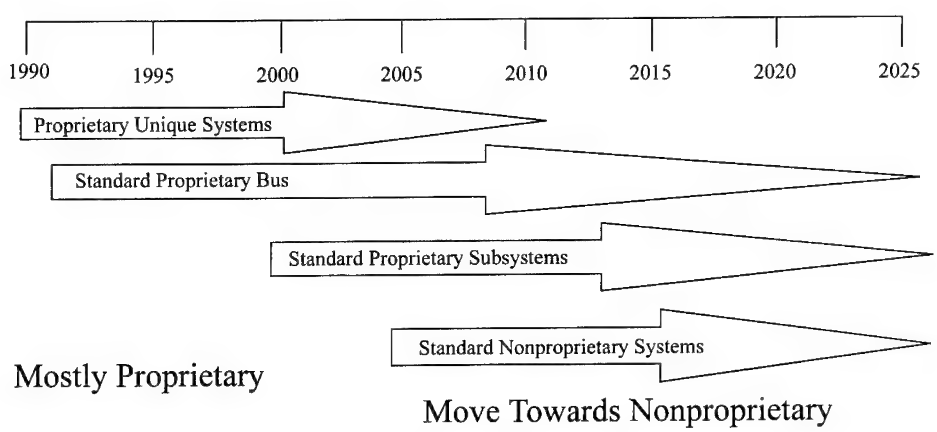

Figure 5-4. Time Line for System Standardization

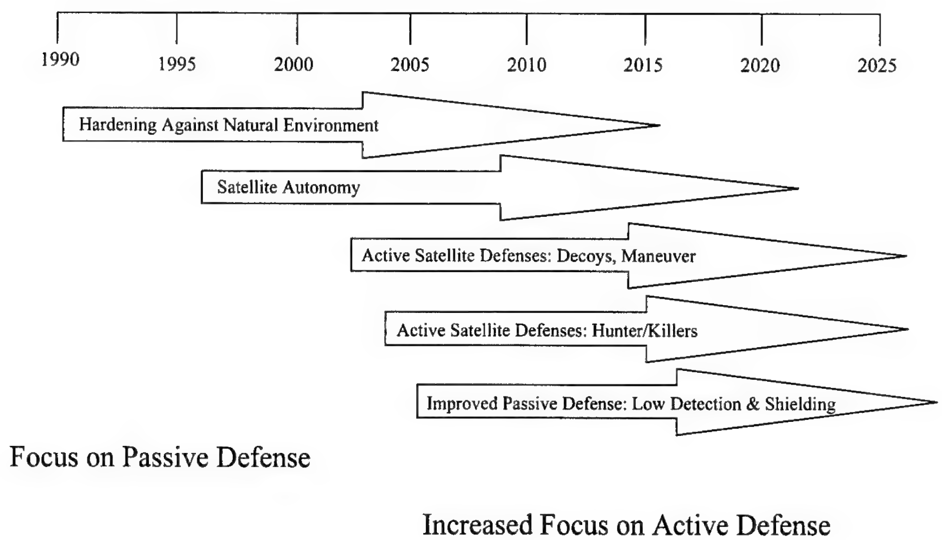

Figure 5-5. Advances in Satellite Defensive Systems

did in the early days of the Internet. Other technologies in the final category are most clearly DOD-unique requirements or high-risk, and expensive development programs.

Technologies the Air Force should expect the commercial sector to lead:

1. Telecommunications
2. Computers and data storage (both terrestrial and spaceborne)
3. Software and artificial intelligence
4. Miniaturization (electrical and mechanical)
5. Common/standard space subsystems and components

Technologies the Air Force/US government should provide incentives for:

1. Radiation-hardened electronics
2. High-bandwidth communication capabilities (laser cross-links)

Technologies the Air Force/US government should lead:

1. Space-based, common C^3 system
2. Satellite defensive measures (active and passive)
3. Revolutionary propulsion (nuclear, electric, laser)

Conclusions

The spacenet system meets or exceeds the applicable measures of merit relevant to the alternate futures of 2025. The paths are feasible to achieve the key technologies of the Spacenet 2025 system. These paths require an *evolution* of some technologies and some technological *revolutions* as catalysts to lead the system evolution. Three categories of recommendations suggest ideas that the Air Force should consider to stay on track to achieve the spacenet system by 2025.

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Procurement in 2025: Smarter Ways to Modernize

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Executive Summary

Defense spending, lacking the threat of general war, is unlikely to grow between now and 2025. The onrushing balanced budget era spells even more trouble for defense. Annual debates over personnel costs, readiness, operation and maintenance (O&M), and procurement will increase heat but offer little light. In an austere environment, our current procurement practices will either saddle the Air Force with outmoded systems or cause us to swap force structure for increasingly expensive new systems. Neither outcome serves our nation well.

The defense industry has changed since the cold war ended. Large firms have absorbed smaller ones. Other large firms have merged with former competitors. More consolidation seems inevitable. This shrinkage reflects economic reality—there are too few procurement dollars to support the cold war defense industry. Presumably, surviving firms are the fittest; and national security demands a healthy defense industry to protect vital industrial capabilities.

The Air Force expects the aerospace industry to produce weapon systems that touch the outer limits of technology, that are sustainable within the Air Force logistics system, and that have reasonable prices. Given that the aerospace industry had to downsize, it is not clear what effect downsizing will have on procurement policy. Nor is it clear how downsizing will influence weapon system performance, sustainability, and pricing. One thing is clear: unless procurement policies change, dissatisfaction will continue to exist.

Present procurement practices are *too costly, too highly supervised, too cumbersome, too slow, and too secretive*—and these five dissatisfactions interact. For example, the last four drive the first upward. DOD must radically change procurement practices to reduce these dissatisfactions.

The following pages discuss changes that should occur. The way major contracts are awarded tops the list. DOD should award only design, engineering, and final assembly contracts to aerospace firms. The remaining contracts for most parts, subassemblies, and systems should be awarded directly to firms in the cost-effective, commercial sector. Computer aided design/computer aided manufacture (CAD/CAM) technology makes outsourcing a practical, low-cost method for manufacturing. DOD needs fresh faces from nondefense industries—and a better comprehension of modern industrial practices—in order to institute these changes.

The cost burdens associated with oversupervision, overinspection, excessive paperwork, and unreasonable security are correctable. DOD imposed some of these burdens; others resulted from congressional overview and intervention. In every case, solutions are possible—and the future Air Force will suffer if present procedures continue without change.

Foreword

The changes suggested in this paper reflect personal experience in military requirements while serving in the Air Force and personal experience in manufacturing after retirement from the Air Force. My civilian experience includes two years as general manager of an aircraft plant that had over 8,000 employees and both military and civilian contracts. Presently I am a parts manufacturer for several well-known companies. Whatever biases appear in this paper stem from 45 years spent in these occupations.

Setting the Stage

In order to look ahead 30 years, one makes assumptions that seem plausible—at least to this author. These assumptions provide a venue for examining tomorrow's policies. Lacking credentials as a soothsayer, the author recognizes that his specific assumptions may fail the test of time. Nevertheless, most of the changes recommended should benefit future procurement policies.

A balanced budget era will occur, sooner or later, and its impact will increase the tension between social entitlements and military requirements. Defense spending in constant dollars will not exceed present levels unless there is general war. Regional wars and excursions may briefly raise the budget threshold, but the additional money will be largely spent on operating costs. The Air Force budget will be tight(er), and internal debate over personnel costs, readiness, operation and maintenance (O&M), and procurement will increase. One positive affect of internal debate will be the realization that *radical* change is necessary in order to accomplish current and future missions. Organizations that don't change, die!

Air Force procurement for weapon systems between now and 2025 will struggle with conflicting factors. New technology will appear, and it will be attractive. However, tradeoffs between force structure and weapon effectiveness could push the Air Force into becoming too small for the worldwide mission or too obsolete to meet then-current requirements. Naval Air Force experience in the Gulf War is a recent example of the latter outcome. Nevertheless, the Secretary of Defense's (OSD) inclination will be to protect force structure from further drawdown. Making do with old systems will be the name of the game unless lower-cost procurement becomes possible.

Economies of scale that were possible in the past will virtually disappear from the weapon system procurement process. The F-16 may be the last Air Force weapon system to enjoy a large production run. The C-17 may be the last transport between now and 2025. The B-2 may be the first weapon system that dies because, among other reasons, Congress and the public do not understand economies of scale. Before this thought is rejected by advocates who see thousands of F-22s and joint advanced strike technologies (JAST) in their procurement gunsights, let me suggest that their optimism will quickly die unless ways are found to dramatically reduce procurement costs.

The "defense industry" we have known will disappear except for a few corporations. The transformation of several firms into what is now Lockheed Martin serves as a classic example The nuptial arrangements between Boeing and McDonnell Douglas were recently disrupted by the timely arrival of a new suitor (Uncle Sam) with a large C-17 contract. But the shrinking process is well under way and the end is not in sight.

Remaining defense firms will be scaled back, will lack the flexibility offered in the past, and will have conflicting interests because of financial opportunities in the much larger civilian market. Corporate mergers and fewer military orders will cause skilled engineers and machinists to migrate to civilian industry where their long-term interests are better served. A worrisome analogy is the dominant position the US once held in nuclear power. When nuclear power became politically incorrect and

career opportunities shrunk, bright young college students avoided nuclear physics and nuclear engineering. Today, world leadership in nuclear power lies elsewhere. Are potential Kelly Johnsons of the future turning away from aeronautical engineering as a career?

The international market will keep the US aerospace industry alive. Boeing remains the dominant commercial aircraft manufacturer in the world because of orders from foreign airlines and resurgent US airlines. McDonnell Douglas stays in the fight for second place despite subsidized Aerospatiale's best efforts. Many nations, particularly third world, still prefer American military aircraft and associated weapons for a variety of good reasons: proven performance, excellent parts support, competitive price, available training, political pressure, and so forth. Will this benign relationship with foreign purchasers help the future United States Air Force (USAF)?

The answer is a complex one. Regional alliances are strengthened when allies use common weapon systems that minimize logistical, training, armament, communication, and planning problems. When production lines in the US can stay open by building aircraft for other nations, the manufacturer is able to maintain facility, production lines, work force, and profitability. This ongoing production offers a relatively inexpensive source for US replacement aircraft and spare parts.

Serious limitations remain, however. Political and economic pressures make it extremely difficult to discontinue production, even though the aircraft being produced has long since been overtaken by newer developments. Meanwhile, inside the facility, machines grow old and outmoded. Engineers are unchallenged while marketing creates briefings to convince Congress and the Pentagon that their sow's ear really is a silk purse.

Without significant new development and production programs, the outlook will not be bright for the military side of US aerospace. Cold war money provided the impetus for developing and building the best military aircraft in the world. But the military side of US aerospace, now leading the world, may lose its dominance as programs dwindle, talent disappears, and technology drifts overseas.

A rough analogy may be the pre–World War II (WWII) era, circa 1941: excellent technology in US commercial aircraft, mediocre technology in US bombers, and mediocre-to-poor technology in US fighters. In regard to technology drifting overseas, we are "whistling in the dark" if we do not recognize that business and government policies which send our technology overseas in exchange for current business will eventually hurt the weakest members of the aerospace industry. If military contractors become the weakest members of our aerospace industry, then we should expect Europe, Japan, China, Israel, and Russia—using proven American technology—to overtake our lead in military aircraft.

The recent skirmish over maintaining air logistic centers (ALC) or privatizing repair was only a partial victory for the ALCs. Political factors obviously weighed heavily in the final decision process, with ALCs being closed in California and Texas. However, the argument that manufacturing skills and expertise could be retained in the aerospace industry through privatization of aircraft repair was exaggerated. *There is little commonality between repairing an old aircraft and manufacturing a new one.* Manufacturing skills are minimized in a repair facility. To illustrate, imagine the different process used to manufacture and assemble an aileron for an aircraft in serial production and the process used to repair the aluminum skin on one aileron. Yet, despite the obvious distinctions between these capabilities, future battles over privatization of the Logistic Centers will favor private industry because of costs and political pressures. Once this conversion has run its course, the Air Force should not

assume that Aerospace Company X's repair facility can quickly become a production facility—and vice versa.

Air Force Materiel Command (AFMC) will continue to consolidate and shrink as the Air Force realizes the huge burden it places on the procurement process. The first sign of this shrinkage will occur when AFMC decentralizes control by moving system program officers to the centers. (Air Training Command [ATC] successfully decentralized years ago.) The Air Force will finally pay more than lip service to the term "empowerment" and follow industry's example. Communications and computers have eliminated the need for many administrative positions—politely called "middle management" in civilian industry. The ax will also fall on the remnants of systems command because most technical work will be privatized. Once privatized, the oversight function should be performed by a smaller staff.

What's Wrong with Procurement Today?

Criticisms abound, and many solutions have been offered by Congress, Pentagon officials, the media, whistle-blowers, and so forth. In my opinion, many criticisms have been shallow and ill-founded. Many solutions were therefore inadequate. But the five basic criticisms persist and are probably correct. They are repeated here: *high cost; too highly supervised; too cumbersome; too slow; and too secretive.*

The number one deterrent to modernization is *high cost*. In the McNamara era, the services accused OSD of using the following rationale for killing most weapons system proposals: "One, we don't need it. Two, even if we need it, it won't work. Three, even if we need it and it works, it costs too much." Except for a brief period in the '80s, the third reason still dominates the decision process. Measuring school lunch programs against new bombers may not be logical, but it rings a sympathetic bell with John Q. Public. The net effect of constantly escalating procurement costs has been a steady decline in force structure. All of the assumptions listed earlier suggest the upward spiral will continue unless radical change occurs.

Defense procurement is *oversupervised* from top to bottom. Congress, reacting to "$600 toilet seats" and similar minutiae, has imposed a bureaucratic nightmare of reviews, regulations, and policies. OSD, not to be outdone, layers programs with excessive review and more regulations. In turn, the secretaries of the Air Force impose themselves and their staffs into the supervisory role. The air staff and major commands expend increasing resources and time on program management, answering/ asking questions, and telling AFMC personnel how to do their job. AFMC links the entire supervision chain with industry and is a sinkhole for even more money spent on supervision. And finally, at plant level, military inspectors inspect the already inspected. The defense industry maxim, "Give 'em the parts, charge 'em for the paperwork!" reflects industry's attitude toward this bureaucratic nightmare.

Procurement costs in the defense budget do not include the costs of government supervision for specific programs. If government supervisory costs were allocated as program overhead, individual program costs would be significantly higher. It would be a real eye opener to include a rough estimate of all these hidden, supervisory costs in any big program. Start with the average hourly wage of the government workers (blue suit, civilian, congressional OSD, administrative), add fringes and overhead, multiply by man-years, then add the total to program overhead. This number would show Congress and senior defense officials the unhealthy contrast between the extremes of "Sam Walton"-type management and military pyramid management. A healthy, cost-conscious system would eliminate most intermediate supervision.

The entire procurement process is *too cumbersome* and complex. Businesses hesitate to seek government contracts, even when production levels are reasonably high. Philip Odeen, President and Chief Executive Officer of BDM International, Inc., and Chairman of the Defense Science Board's task force on privatization, makes this same point. When production levels are low—the norm in future years—more businesses will avoid government contracting. The reason for avoidance is simple: commercial business is more profitable and has fewer headaches, often leaving "bottom fishers" competing for the few government contracts available.[1]

Military procurement is *too slow* by any reasonable standard. Weapon systems take too long to get approval; too long to build; too long to test; and too long for any company, except within the subsidized defense industry, to accept the risk involved in making a profit. The advanced manned strategic aircraft, "AMSA," a.k.a. B-1, is the classic example. First postulated as a requirement in 1962, it was studied throughout the '60s, prototyped in the '70s, killed by President Carter in 1977, resurrected by President Reagan in 1981, produced in the '80s, and finally reached limited combat utility in the late '90s! Meanwhile, Air Force determination to "hang in there" with the B-1 has caused alternative proposals based on better technology to be placed on the back burner.

The procurement of new weapons is *too secretive.* Secrecy costs big money and big time. Secrecy denies the American public the opportunity to become aware of the merits of an expensive project during development when political support is badly needed. Secrecy prevents the military from defending projects which are attacked by media know-nothings.

On the other hand, publicity about big projects can produce salutary effects. When President Johnson disclosed the SR-71, the public response was enthusiastic and supportive. When President Carter disclosed (to the dismay of the military) the stealth fighter, public response was once again positive. The Strategic Defense Initiative (SDI), labeled "Star Wars" by the media, may or may not have been an effective weapon system but the *economic* consequences of competing with SDI overwhelmed Soviet leaders. The sad news about our efforts to maintain secrecy during procurement is that leaks and compromises usually result in premature disclosure anyway.

The notion that every production worker on a major weapon system has to have a secret or higher clearance should be critically examined, then discarded as nonsense. As a starting point, workers on parts and subassemblies are unable to determine performance or system characteristics because of their limited exposure to the entire project. Once a weapon system begins production, enough lead time has been established over copy-cat foreign systems so that the cloak of secrecy could be removed, costs reduced, and production simplified. Let the manufacturer worry about disclosures to competitive US firms.

Changes That Are Occurring: "Use Commercial Practices"

Manufacturers that depend upon government contracts do not compare in efficiency with commercial manufacturers in the same industry. Defense contractors blame their inefficiencies on a blizzard of government regulations and policies—an excuse that is not without merit. "Red tape" costs both time and money; it partially explains why overhead can be two or three times higher than overhead in comparable commercial companies. Large corporate staffs, low worker productivity, excessive salaries, generous retirement benefits and other fringes, and restrictive union work rules all add to the problem. These systemic inefficiencies accelerate costs and can jeopardize major programs. Early Air Force audits of C-17 production nearly caused program termination; a bad situation

corrected only after McDonnell Douglas made major management changes.

Arcane language and excessive detail make government contract proposals a real challenge to the uninitiated contractor. Too often, contractors shy away from bidding because of their unfamiliarity with complex government regulations and policies. And those who do bid often feel compelled to hire consultant teams to translate requests for proposals and to prepare bids.

Simplifying the process should begin with defining the military requirement. The Air Force should clearly state overall objectives, but avoid describing detailed specifications. Commercial engineers contend daily with the state of the art; military planners do not. Therefore, commercial engineers can optimize the requirement if given some latitude. This is particularly true with fast-changing electronics and information systems.

The regulation and policy problem is perpetuated by high-ranking DOD civilians who are appointed to public office from defense industries. They are appointed because they "know the ropes" of defense contracting. Without accusing these officials of intentional wrongdoing, it seems obvious that the culture which provided their experience is the same culture that needs to be replaced. DOD needs fresh faces from nondefense industries.

If procurement costs are too high under the present procurement process, then change the process. Various efforts are already under way to improve contracting with private industry. Among the first is a directive to adopt "common processes by contractors in lieu of multiple, unique DOD standards and specifications."[2]

Secretary William Perry, on 6 December 1995, recognized that while "it is generally not efficient to operate multiple, government-unique management and manufacturing systems within a given facility, there is an urgent need to shift to facility-wide common systems on existing contracts as well."[3] Secretary Perry directed Under Secretary Kaminski to promulgate guidance to the Directors of Defense Agencies to carry out his instructions.[4]

Give DLA credit for good intentions. However, "the devil is in the details." The memorandum requires the contractor to convince the government that implementing the common process in lieu of milspecs and standards on existing contracts will be advantageous to the government, will encourage the use of advanced practices, will eliminate non-value-added requirements, and so forth.[5] The "common processes" initiative will become as objectionable as existing Mil standards if the government sits as judge and jury on how to make a product. The government must learn and practice the leadership maxim: "Tell them what to do, but not how to do it." Nevertheless, the SecDef directive is a sign of progress.

Today's American manufacturers compete worldwide for contracts. This highly competitive marketplace forces survivors to control costs while constantly improving quality. Successful manufacturers have newer machine technology, better engineers, experienced machinists, efficient factories, lean-and-mean staffs, motivated managers, and low general and administrative (G&A) costs. Absorbing more production is relatively inexpensive in such a company and results in manufacturing *economies of scale.* Companies fitting this description want government contracts only if government "experts" do not tell them how to run their business. If the government insists on telling such companies how to operate, thus continuing the bureaucratic nightmare, potential cost savings will disappear.

Changes That Should Occur: "Flatten the Procurement Chain"

Weapon system contracts are normally awarded to a prime contractor who typically includes other major defense contractors as part of the team. The prime and majors then turn to subcontractors for major components. The subcontractors then outsource part of their responsibility, and so on down the food chain. At each layer, the process includes oversight, inspections, paperwork, and *profit.* Figure 1 illustrates this multilayered arrangement.

The compounding effect that multi-layered procurement has on costs is very significant. Consider an example where the gross profit at each stage of production is 20 percent and there are only five stages of production. Assume the part is an ejector that costs $640 for the parts supplier to make. Component supplier buys the ejector for $800, assembles the part in a thruster assembly, then sells to sub #1 for $1,000. Sub #1 builds and sells the engine chamber to a major subcontractor, the ejector representing $1,250 of the price. Major subcontractor attaches the engine chamber to the complete engine assembly and sells the entire propulsion system to the prime contractor for $1,562. Prime then sells the weapon system to the Air Force, the ejector representing $1,952 of the total price.

Now imagine a streamlined, alternative procurement system as depicted in figure 2. In this system, the prime is paid for engineering design and contract management. "Design" includes the selection of all major components and subsystems. Computer aided design/computer aided manufacturing (CAD/CAM) is the common denominator used in all these production arrangements. It allows the prime contractor to work directly with major and secondary subcontractors, thus eliminating at least one markup. Subcontractors can work directly with component suppliers, and parts suppliers using CAD/CAM and eliminating at least one more markup. Final assembly should be outsourced as a specialized function.

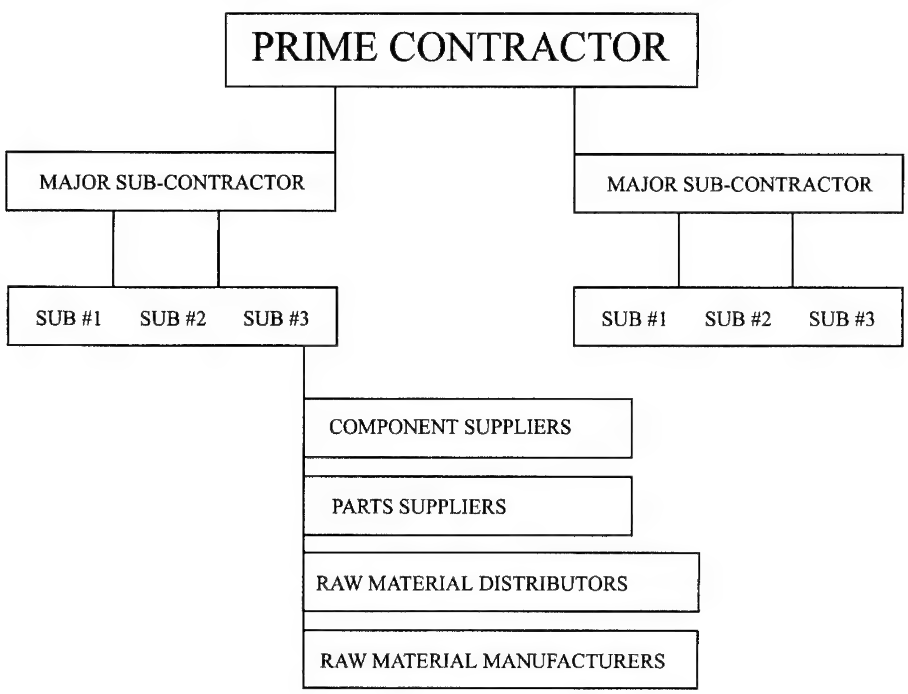

Figure 1. A Typical Production Arrangement

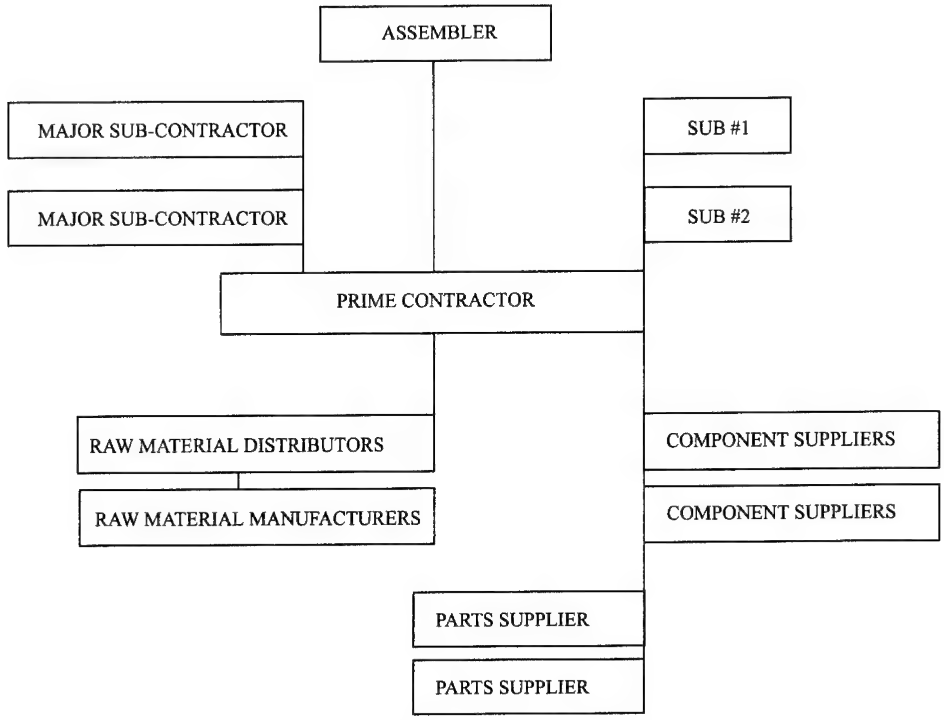

Figure 2. Contract Management by Prime Contractor

Selection criteria would emphasize the requirement for an existing plant, machinery, and work force.

This flattened procurement system would work because CAD/CAM works. It eliminates the error-ridden dependence on blueprints. When fed directly to three-, four-, and five-axis computer numerically controlled (CNC) machines, precision parts are the result. Quality is improved and inspection costs are reduced. When the major components are ready for assembly, they fit and meet all specifications.

Another way to reduce the effect of progressive markups is to limit the amount that contractors can markup their purchases from subcontractors. Take the ejector example. A cap of five percent at each stage after the initial sale price of $800 would reduce the cost of the ejector to the Air Force from $1,952 to $1,033. Some companies are already following this procedure voluntarily.

Changes That Should Occur: "Minimize Investment in Plant and Equipment"

DOD wastes procurement dollars by including the costs for new plants and machines in a major program. Building and equipping plants at Palmdale and Pico Rivera were major cost factors in the B-2 program. Rockwell had to rebuild for the B-1 program. Now that downsizing has hit defense procurement, scarcely a week goes by without some defense manufacturer auctioning machines and other equipment at fire sale prices. Most items are vintage 1980s or older, purchased for procurement in the cold war and outmoded in modern factories.

Bureaucrats may find comfort in clichés that dismiss this waste: "sunk costs"—"before my watch"—"water over the dam"—"spilt milk." But there is little excuse for building a defense plant, buying new machines,

hiring and training new workers, and so forth, when existing manufacturers can produce the same article by using or augmenting existing facilities. Separating design and contract management (prime contractor) from assembly (major contractor) will minimize this waste.

In most cases, contractors should use their own facilities. In other cases, Air Force assembly plants could be leased at minimum cost to contractors for aircraft assembly; for example, the contractor pays only utilities, insurance, and leasehold improvements. The assembly contract award should be heavily influenced by comparisons regarding depreciation, utility costs, availability of production workers, adequacy of machinery, jigs, and so forth. Separating assembly contracts from design and program management contracts would avoid situations where there is a mismatch between performance requirements (design) and production capabilities (plant and machinery). The Air Force should also avoid the notion that sharing a facility with commercial production is a no-no. Sharing facilities can create major savings.

Changes That Should Occur: "Attack Oversupervision"

Mentioned earlier are descriptions of procurement oversupervision by Congress, Secretary of the Air Force, OSD, the Air Staff, AFMC and other MAJCOMs, DLA, the SPOs, and plant representatives. All this staffing means time and money, as well as delayed decisions and immense overhead for contractors.

What to do? Change Congress . . . too tough. Change OSD . . . not unless you believe the tail can wag the dog. Change DLA . . . some progress might be possible if SecDef approved. Change Air Force—real change is possible.

The 1997 proposed defense budget allows the Air Force about $9 billion for procurement and $9.7 billion for research and development. Together they comprise 31.7 percent of the $58.9 billion total Air Force budget. *Defense News* stated, on 4 March 1996, "defense officials point to expenditures planned for 1998 through 2001, when procurement funding is slated to increase by 40 percent."[6] (Reminiscent of "the check is in the mail!") Nevertheless, the dollars available for procurement and research and development (R&D) have been drastically reduced from the recent past. Air Force needs to stretch the remaining dollars to cover essentials. Oversupervision is expensive and unnecessary. It wastes dollars that could be better spent on essentials.

The Air Force recently combined responsibilities for procurement and research and development within one command. The next steps should restructure this command by separating "line" and "staff and oversight" responsibilities. Start with R&D. How many civilian and military persons are actually involved in research? Would consolidation of Air Force labs reduce overhead? Would substituting civilian contracts for Air Force labs reduce "tail" and allow more "tooth"? How many "staff and oversight" people are required to manage R&D?

Imagine for a moment that one-half ($4.8 billion) of the R&D budget is spent in Air Force labs or working on projects that require "blue suit" scientific and engineering skills. The Air Force should compare costs with a $5 billion civilian company engaged in high-tech research and development. Does Air Force R&D require more people than the commercial R&D company? If so, why?

Switch to the other half of the R&D budget—the oversight responsibility for contracting, programming, and project monitoring. Is it reasonable to spend this much (pick your favorite number) on staff activities? Once again, the commercial model with similar sales is worth examining.

Procurement is proposed at $4.5 billion for 1997. Since most of the money goes to contracts, the problem boils down to reducing costs by reducing contractor overhead. This means fewer reports to the government, fewer meetings between company staff and government officials,

fewer audits and inspections, and fewer government directives. Insistence on sensible warrants and guarantees would offset the reduction in government supervision.

Overinspecting has been another irritating, time-consuming, and costly aspect of government procurement. There was a time, circa 1950–75, when most US factories were oblivious to modern quality techniques. To protect itself, the government subjected major purchases to an elaborate inspection system involving both commercial and government inspectors. Quality management has changed dramatically in the past 20 years. The Deming Revolution, first felt in the Japanese auto industry, has now migrated to the United States and Europe. The notion that one could "inspect-in" quality is dead. Instead, today's emphasis is "build it right the first time."

The problems with overinspecting are at least threefold: (1) costs too much; (2) shifts responsibility from the worker to the inspector; and (3) doesn't solve systemic problems. Successful quality now depends upon statistical process control, worker empowerment, CAD/CAM, CNC machines, worker training, raw material verification and traceability, vendor qualification, modern calibration equipment, reliability testing, and so forth.

A universal quality standard called "ISO 9000" has been created. Companies qualified under ISO 9000 must meet certain quality standards that are respected worldwide. The drawback to ISO 9000 is that it emphasizes bureaucratic procedures and documentation over product quality. To oversimplify, ISO 9000 qualification means that a company is actually doing what it says it is doing and can prove it with paperwork. In most cases, companies that adhere to their ISO 9000 procedures will have quality products. But the Air Force should proceed with caution before Mil standards are discarded in favor of ISO qualification certificates.

Changes That Should Occur: "Outsource Depot Repair"

Using DOD employees, USAF depots in 1994 accomplished approximately $2.6 billion in repair and maintenance work. Commercial companies accomplished another $1.3 billion. About 85,000 DOD workers were employed for repair and maintenance work in 1995. The number will shrink to about 80,000 DOD employees in 1999. John White, Deputy Secretary of Defense, stated on 16 October 1995, that outsourcing to defense contractors should shrink the expenditures on overhaul and maintenance by 15–20 percent.

Several factors support White's opinion. Defense contractors would probably be more efficient than government facilities, so the estimate is not unreasonable. Start with Air Force Logistic Center (AFLC) management. The Air Force selects excellent major generals to run these large facilities. Sometimes they are experienced logisticians who have spent years in supply and maintenance. Others come with a background in operations and operations staff work. To the best of my knowledge, neither the logisticians nor the operators have managed a production facility with thousands of employees before commanding an AFLC. Usually they serve two or three years in this job and then move. These excellent officers are "a mile wide and an inch deep" in technical know-how. They are assisted by other officers with similar credentials. Intermixed are career civilians who honed their skills in the civil service and provide institutional memory that keep the AFLCs on even keel.

The contrast at the top between AFLCs and commercial factories is apparent. Chances are that top managers in a commercial factory have spent years learning their business. They tend to be "an inch wide and a mile deep" in technical know-how. They are comfortable in a corporate culture where the emphasis lies on the bottom line. Survivors of their selection process know how to cut

production costs, know when a project is in trouble, understand balance sheets and income statements, and know that plant performance will determine their future livelihood. Would you pick an excellent general or an excellent plant manager to run your factory?

We need not dwell on comparisons of direct laborers to recognize that job stability in the commercial world suffers in comparison to government employment. The downside of instability is that commercial workers are less loyal to their employer. The upside is that productivity standards can be set higher for commercial workers. (Don't produce, get fired.)

Granted, the above comments are largely subjective. One additional comment is not subjective, however: the profit motive. Air Force Logistic Centers operate on a budget. Success is staying within the budget while meeting maintenance and repair objectives. The commercial facility also operates on a budget and must meet maintenance and repair objectives. Failure means the commercial contract is canceled or not renewed. The final measure of success in the corporate world is profitability. Contract termination hurts profitability. This emphasis on profitability stands behind most commercial decisions and is an economic discipline not evident in government. White is right; the Air Force should expend its talent and resources on the "tooth and not the tail" except when operational necessity dictates.

Changes That Should Occur: "Speed and Simplify"

The American judicial branch of government recognizes and respects the importance of precedence. However, the American legislative and executive branches ignore precedence when it comes to defense issues. With little regard to past program authorizations and appropriations, next year's authorizations and appropriations are stretched, altered, changed, or deleted by Congress and/or the executive branch. Previously mentioned was the 35-year saga of the B-1 from inception to almost combat-ready. The inevitable results are higher costs and a weapon system old before its time. Multiyear authorizations make good business sense and would partially correct the problem. However, persuading Congress or OSD to keep hands off previously approved programs is not for the faint of heart.

Changes That Should Occur: "Reduce Classification Costs"

Classification costs *can* be reduced. Whether they *will* be reduced depends upon the Pentagon. Most future procurement for the Air Force begins its life cycle in the Pentagon. There is very little reason for Air Staff action officers to minimize classification. Top secret and secret papers seem more important than confidential or unclassified papers. When in doubt, the staff overclassifies. Once anointed, the overclassification usually sticks.

Classification costs a lot of money over the life of a program. The most effective control mechanism in the Air Force is the budget. The air staff should establish a hard-nosed colonel with a small staff who computes the lifetime costs for security of classified programs. These costs should be clearly identified and only then approved as budget items. Enhancing visibility will force logical tradeoffs.

Many years ago, the Air Force realized that it was impractical to impose maximum security on all aspects of a military base. Instead, we relaxed security measures in areas where the risk of compromise or sabotage was low and tightened security in areas where valuable assets were stored or where war plans could be compromised. The same attitude should prevail when we are dealing with security at defense plants. Most industrial facilities are careful about security (badges, fences, inventory audits, proprietary disclosure statements, safes, passwords for computers, etc.). These self-imposed security measures are adequate for

nearly all plants that could manufacture military systems. As mentioned previously, piling government security measures on top of these existing measures costs too much and severely restricts manufacturing operations.

Conclusion

The twentieth century began with the invention of flight. It ends with aircraft and space vehicles being the dominant military force. As sure as grass is green, the revolution in warfare will continue. The Air Force must grasp the future with one hand while reaching for its wallet with the other. It must convince an unsure nation that it is able and willing to pay the modernization bill that accompanies the twenty-first century. Modernization by 2025 begins by changing procurement policies now.

Notes

1. Interview with Philip Odeen as reported in *Defense News*, 4–10 December 1995, 45.

2. "Adoption of Common Processes at Defense Contractor Facilities," memorandum from Maj Gen Robert W. Drewes to Defense Contract Management commanders and the commander, Defense Contract Management Command International (11 December 1995): 1.

3. "Common Systems/ISO-9000/Expedited Block Changes," memorandum from Secretary William J. Perry to the military department secretaries, the chairman of the Joint Chiefs of Staff, the under secretary of defense for Acquisition and Technology, and other addressees (6 December 1995): 1.

4. "Single Process Initiative" memorandum from Paul G. Kaminaid to the military department secretaries, the chairman of the Joint Chiefs of Staff, the under secretary of defense (Comptroller), and other addressees (8 December 1995): 1.

5. "Adoption of Common Processes at Defense Contractor Facilities," memorandum from Maj Gen Robert W. Drewes to Defense Contract Management commanders and the commander, Defense Contract Management Command International (11 December 1995): attachment 2, page 2.

6. "Critics Question Adequacy of DoD Weapon Funding," *Defense News*, 4 March 1996, 37.

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Aerospace Sanctuary in 2025: Shrinking the Bull's-Eye

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Executive Summary

There is nothing more difficult to take in hand, more perilous to conduct, or more certain in its success than to take the lead in the introduction of a new order of things.

—Niccolo Machiavelli
The Prince

Future technologies may allow a direct reduction of core entities[1] or centers of gravity on an operating air base. Reducing the core entities has a direct impact on base defense. As fewer things become critical for sustained operations, defending them becomes easier. Further, there is a direct synergism in operability and defense. The same technologies that improve operability by making it easier to complete the mission or by reducing the cost of doing business also reduce the number of core entities, thereby reducing defense requirements.

On the air base of 1996, there are many core entities. Degrading or destroying any of the ascribed core entities could degrade mission accomplishment. For the aerospace base of 2025, very few things should be core. This paper identifies the concepts to use emerging technologies that have the potential to create a land base that may be considered an integrated system which provides a sanctuary; capable of sustaining operations regardless of threat, location, environmental condition, or type of mission.

First, the base can be harder to find and therefore target. This situation is accomplished by reducing the number of people, assets, buildings, spare parts, and so forth on the base. Reductions are possible for several reasons: an increase in the reliability and maintainability of everything on the base; the use of robotics for tasks not requiring human inputs; and a reduction of bomb dump size as munitions get smaller. Ambient temperature superconductivity could allow redundant, dispersed power generation, eliminating exposed power grids. The structures that remain could take advantage of material advances provided by nanotechnology and microelectromechanical systems (MEMS) to mask or reduce external infrared, radar, and visual signatures. These technologies could offer improved hardening to reduce damage should an adversary successfully prosecute an attack.

Second, the future base can be guarded by a ground-based multispectral sensor system integrated with and augmented by air and space sensors. Information from these sensors could be fed into an integrated command and control system which also controls or directs the base's response to an attack. Response could come from ground-based directed energy weapons, smart mines, "enhanced" human

response teams with lethal and nonlethal capabilities, and armed unmanned aerial vehicles (UAV). The base could also be covered by a microwave energy shield able to translate the kinetic energy possessed by inbound weapons and use it to repel those weapons. The end result is a self-contained, self-protecting aerospace base.

If the base is actually damaged, the next concept envisions structures, runways, and taxiways able to determine the level of damage and initiate their own repairs. Chemical or biological contaminants could be detected and cleanup started using enzymes or catalysts resultant of advances in biotechnology.

It is assumed that the US may still need to deploy to forward bases.[2] The final concept draws upon advances in nanotechnology, MEMS, biotechnology, and methods of power generation which could allow the deployment, buildup, sustainment, and redeployment of an aerospace base including runways, buildings, and defenses with an order of magnitude less lift. In this vision of the future, runways could be created anywhere with air-dropped materials, while precision air-dropped structures self-erect or are organically grown onto a previously emplaced skeletal frame.

All of these concepts portend a revolutionary way of viewing aerospace base operability and defense. Today's air base is a necessary evil. It is expensive, large, and hard to defend. The aerospace base of 2025 will still be required; however, it should cost less, be much easier to operate, and be self-defending. The ability to position airpower assets anywhere in the world—based only on a set of coordinates instead of being tied to preexisting infrastructure—makes the aerospace base of 2025 a force enhancer rather than the mere force supporter of today's Air Force.

The conceptualization of (aerospace) basing as enhancing rather than merely supporting may foster a renaissance in thinking about the way the US applies military power. Today's forward operations are restricted by basing requirements, that is, water and runways. With the advances identified in this paper, air and ground power can go anywhere—together if desired. This, in turn, may offer unparalleled opportunities to improve the organization of joint operations or even the services themselves.

Notes

1. Dr Karl P. Magyar, "Conflicts in the Post-Containment Era," in Earl Weaver et al., eds., *War and Conflict Textbook*, vol. 1 (Maxwell AFB, Ala.: Air Command and Staff College, August 1995), 15. Dr Magyar's Security Levels of Interest Model has been adopted by the team to represent the core, intermediate, and peripheral components or entities of an aerospace base to correspond to the respective components or entities functional importance to sustainment of the aerospace base mission. This concept is explained in detail in chapter 1.

2. Jeffery R. Barnett, *Future War: An Assessment of Aerospace Campaigns in 2010* (Maxwell AFB, Ala.: Air University Press, 1996), xxv. The author directly implies that the United States will continue to use the military to respond to varying types of overseas contingencies. Peacekeeping, humanitarian, and disaster relief operations are examples which seem to be part of the United States's charitable ethic and will demand the maintenance of a capability to deploy forward.

Chapter 1

Introduction

Petty geniuses attempt to hold everything; wise men hold fast to the key points. They parry great blows and scorn little accidents. There is an ancient apothegm: he who would preserve everything preserves nothing.

—Frederick the Great
Instructions for His Generals

In 2025, dominance in aerospace is possible, if and only if, the aerospace base is specifically designed to be a sanctuary for aerospace operations. Yet, with aerospace dominance enabled by networked, brilliant, multispectral sensors, no adversary can hide. Ill intent or aggressive action is met by near immediate response. Manned and unmanned air and space systems target and attack with unrelenting precision.

Thus, adversaries could target the key infrastructure that enables aerospace dominance. The United States (US) will potentially ". . . face threats from one or more sources: a successor state to the former Soviet Union armed with a large, diverse, and advanced long-range nuclear arsenal; a "second-rate" nuclear power with strategic forces resembling those now possessed by Britain, France, and China; or a developing state deploying a moderate number of ballistic missiles capable of hitting the United States."[1] A military peer or niche adversary could potentially attack the US with advanced weapon systems, including precision guided munitions or directed energy weapons based from airborne or space-based platforms.[2] The network of commercial, space-based, multispectral sensors, with the capacity to identify and pinpoint high-value assets and low-cost global positioning system guided missiles to attack them, could be available to anyone willing to pay the commercial fee.[3] Conversely, the US could remain vulnerable to low-technology attacks on aerospace bases in 2025 by an inferior adversary attempting to negate its overwhelming technological advantage.[4] Even today, post-Gulf War analysis by some third world countries has led to this conclusion. Indian brig Vijai K. Nair hypothesized that enemy special forces raids against United States Air Force forward bases and logistics concentrations, though sure to be costly, could produce disproportionately significant results.[5]

The relevant question is whether to even have forward operating bases in 2025 given the disproportionate effects of an attack by a determined adversary? While air and space force projection will predominately be continental United States (CONUS) based, the US could still require the use of forward airfields for reasons related to its position as a world power, its charitable ethic, conflict containment, and coalition force considerations.[6] These are factors which demand a physical presence, especially those related to peacekeeping, humanitarian, and disaster relief, and do not readily conform to operations based exclusively from CONUS.[7] Assuming that not all forward deployed operating areas will have suitable facilities,[8] the requirement to maintain a force deployment and beddown capability could be essential to air and space force projection. This requirement entails forward deployed aerospace bases to be fully automated and integrated facilities, similar to CONUS bases, with the added attribute of mobility.

Forward operating bases will not be able to rely on distance from the forward edge of the battle area, or its equivalent in 2025, as the principal means of protection from attack.[9] The base (including CONUS bases) will have to defend itself against a broad spectrum of threats. The nature of the challenges posed by the 2025 threat environment require a redefinition of operability and defense.

In 2025, operability and defense is the ability to mount and sustain aerospace operations regardless of the nature of threat, level of conflict, environmental conditions, and/or geographic location.[10] A key aspect of operability is the defense of those components or systems deemed critical to support of the aerospace base's mission. This analysis will demonstrate that by capitalizing on specific emerging technologies, the capability to enhance aerospace operability and defense is attainable by significantly reducing the number of aerospace base "core entities," and thereby increasing the base's survivability, if targeted and attacked.

Core is defined as the central, innermost part of anything, the most important part,[11] and *entity* is a thing that has definite, individual existence in reality or in the mind; anything real in itself,[12] hence the derivation of "core entity(ies)." Accordingly, and within the context of this thesis, a subordinate function will be to define those core entities which are most crucial to operability and potentially the most likely targets of an adversary. The analysis will also identify, but to a lesser degree, those elements of the aerospace base which are defined as intermediate and peripheral entities (i.e., nondecisive points or components). The end result of this identification process will illustrate the technological means to migrate those entities presently categorized as core entities outward into the intermediate and peripheral categories (see fig. 1-1). Reducing the number and dispersing the key base functions, that if attacked, would halt operations, could reduce base vulnerability, and increase operational effectiveness. Said another way, by substantially reducing the number of core entities present on an aerospace base, the defense required to protect those remaining core entities is scaled proportionately. However, there is a resultant trade-off between defense and the number of core entities. It may be technically feasible to reduce the number of core entities but is economically infeasible. The converse is true, it may be expensive and difficult to reduce the number of core entities, but necessary because it may be even more difficult or more expensive to protect them.

Today, operability and defense is considered a force support mission, similar to logistics and combat support.[13] The role of force support is to ". . . support and sustain the aerospace combat roles of aerospace control, force application, and force enhancement."[14] In 2025, improvements in the survivability, reliability, adaptability, defensibility, and mobility of an aerospace

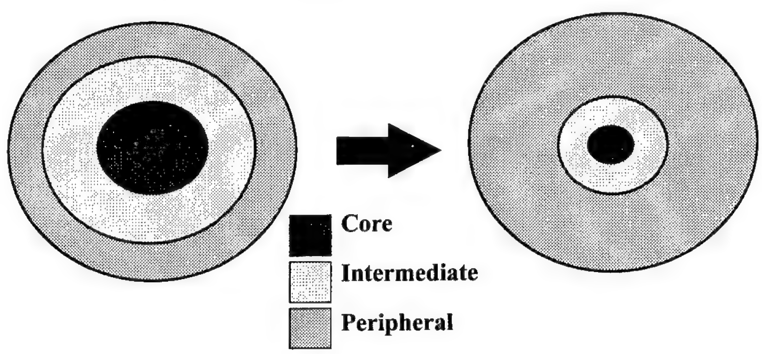

Figure 1-1. Migration of Core Entities

base could transform operability and defense into a force enhancement mission. As shown in figure 1-2,[15] this conversion elevates aerospace base operability and defense to the level of airlift, aerospace replenishment, special operations, and information operations—force enhancers—with the capability to ". . . increase the ability of aerospace and surface forces to perform their mission."[16]

Although the full ramifications of this concept are not completely clear, its fulfillment signifies a tremendous expansion in the capability of airpower force projection. Completion of the aerospace base metamorphosis will involve a counter-balancing trade-off between the migration (reduction) of core entities and increasing defensive capabilities. Whichever objective the cost/benefit analysis supports, the ability to operate and the necessity of defense are inseparable and leverage many of the same technologies anticipated to be available in 2025. The following chapter identifies the capabilities required to operate and defend an aerospace base of 2025.

Notes

1. Institute for National Strategic Studies (INSS), *Project **2025*** (Norfolk, Va.: National Defense University, 6 May 1992), 45.

2. Jeffery R. Barnett, *Future Wars: An Assessment of Aerospace Campaigns in 2010* (Maxwell AFB, Ala.: Air University Press, January 1996), 27–28, 76–77.

3. Ibid., 1.

4. David A. Shlapak and Alan Vick, *Check Six Begins on the Ground, Responding to the Evolving Ground Threat to U.S. Air Force Bases*, RAND Report NR-606-AF (Santa Monica, Calif.: RAND, 1995), xv.

5. Brig Vijai K. Nair, *War in the Gulf, Lessons for the Third World* (New Delhi: Lancer International, 1991), 225–28.

6. INSS, 46–47.

7. Ibid., 47.

8. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century* (unpublished draft, the mobility volume, 15 December 1995), 37.

9. Barnett, xxv.

10. Team-derived definition of operability and defense for purpose of thesis development.

11. *Webster's New World Dictionary of the American Language*, 2d ed., s.v. "core."

12. Ibid., "entity."

13. AFM 1-1, *Basic Aerospace Doctrine of the United States Air Force*, vol. 1, March 1992, 7.

14. Ibid., vol. 2, 285.

15. Department of the Air Force, *Cornerstones of Information Warfare*, n.d., 11. This publication, signed by Gen Ronald R. Fogleman, Air Force chief of staff, and Secretary of the Air Force Sheila E. Widnall, updates the previously established AFM 1-1 Roles and Missions breakout to take into account changes brought on by the rising preeminence of information warfare. The "Cornerstone" model, shown in modified version, is being used as the baseline Roles and Missions model for the ***2025*** Project.

16. AFM 1-1, vol. 1, 7.

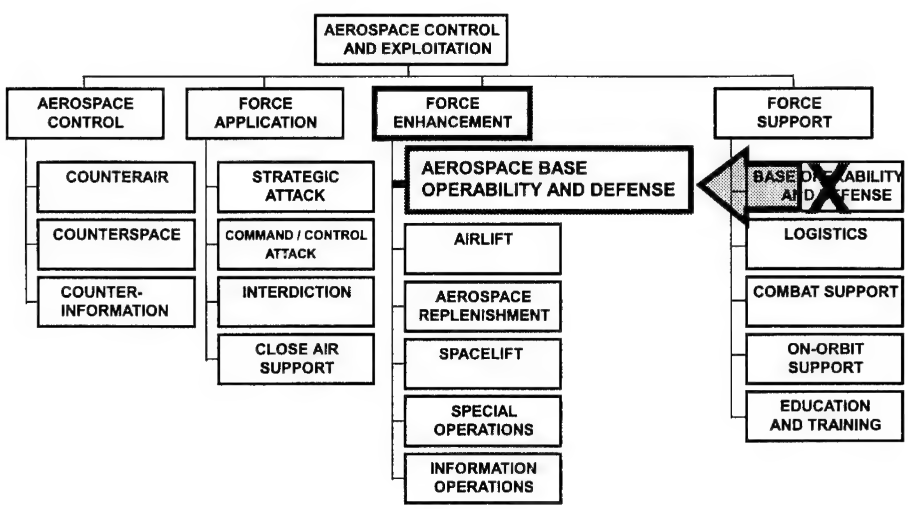

Figure 1-2. Roles and Missions Revision

Chapter 2

Required Capabilities

The secret of success is to have a solid body so firm and impenetrable that wherever it is or wherever it may go, it shall bring the enemy to a stand like a mobile bastion, and shall be self-defensive.

— Comte de Montecucculi
Principes de l'Art Militaire

Overview

This chapter initially reviews operability and defense at today's air base, then enumerates the assumptions which bound the scope of this paper, and defines the worst-case operating considerations in 2025. Lastly, the requirements for a 2025 base will be defined and distributed under the categories of low-observable base, shielded base, self-healing base, and mobile base.

Today's Air Base

Currently, aerospace operations are conducted from three types of aerodromes. The first type is a main operations base (MOB).[1] MOBs are characterized by highly developed infrastructures and support architectures, mostly stateside. The MOB represents an extreme of operating environments and by far the most capable operating infrastructure. The second type of base is called a collocated operations base (COB).[2] A COB is typically owned and operated by an ally and characteristically varies in its state of accessibility and readiness. The final type of base is referred to as a forward operations base (FOB).[3] Most FOBs are extremely austere with little to no infrastructure. When an infrastructure does exist, it is usually poorly maintained or inadequate in some other regard. For the purposes of this paper, the discussion will be confined to the antipodes of operating bases: MOBs and FOBs. Both types of operating bases contain a large number of core entities, including aircraft, runways, aircrews, support personnel, and command post. Current air base defense operations are nested in the overall rear area defense and are the responsibility of the land component commander (LCC) in a theater of operations.[4] Locating air bases in the rear area enhances security as it uses geographical separation from the enemy to one's advantage. Traditionally, rear area defense is a low priority concern, as the LCC's attention is typically focused at the front and the enemy main. Rear units are then expected to provide their own security, and as a result, air base defense commanders are essentially on their own.[5] Consequently, this leads to an imbalance in the relationship between the number of entities needed to be protected and the level of protection available as represented by figure 2-1. The objective is to seek a more measured balance between the core entities of an aerospace base and its defensive capabilities. In order to achieve this objective, the aerospace base of 2025 must be defined with respect to the platforms it must support and sustain. But first, formulation of logical and reasonable assumptions regarding the dimensions of the requirement with respect to the most-demanding-to-support or worst-case scenario must accomplished.

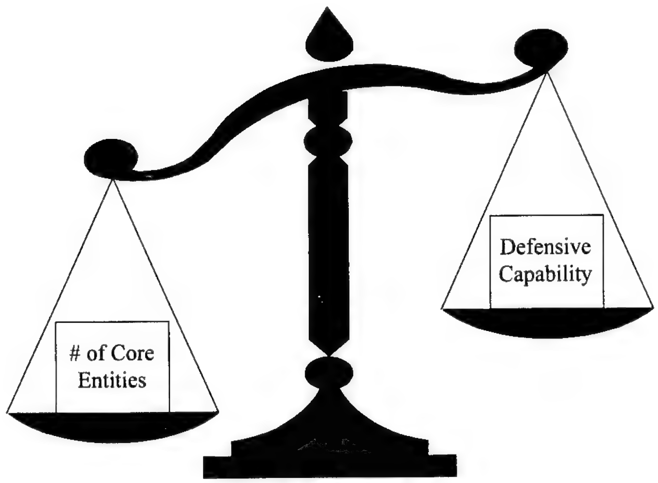

Figure 2-1. Defense/Core Entity Trade-Off

Assumptions about Aerospace Bases in 2025

Aerospace bases in 2025 could assume many varying forms and sizes and support numerous differentiated types of forces. It is then with a focus on the worst-case scenario that the assumptions, in terms of operability and defense, are derived. Three considerations germane to operating and defending a base are size, location, and priorities of the resources on the base. The worst-case scenario is one which requires a runway of fixed-dimensions for horizontal takeoffs and landings and security of high-priority resources in a high-threat environment. This seems reasonable and plausible, since many of the airframes which may be on the ramp in 2025 are either on the ramp today or are in near-term production.[6] It is most likely that a greater number of manned and unmanned aerospace platforms in 2025 will have vertical takeoff and landing (VTOL) and short takeoff and vertical landing (STOVL) capabilities.[7] Presuming that the basing (launch and recovery) requirements for VTOL/STOVL platforms are substantially less than horizontal takeoff and landing platforms, hence easier to sustain and defend, they will not be addressed specifically because they do not meet the worst-case scenario criteria.

As introduced in the preceding chapter, a derived requirement of the 2025 aerospace base is to reduce the core entities required to support the mission. Given this requirement, several assumptions are critical to the analysis. Although not all bases will be the same, the worst-case and possibly the most likely case is that base infrastructure will still include the equivalent of a North Atlantic Treaty Organization (NATO) standard runway (7,500 feet x 125 feet), fuel, ordnance, operators, and maintainers. Supporting this primary force element will be personnel and equipment providing command and control, power generation, water and sewage handling, administration, billeting, medical/dental services, security, and other necessary infrastructure maintainers and systems. Although the number of people, types of systems, and the methods used may change, the necessity to perform these functions should still exist. On CONUS bases of 2025, it may be necessary to protect high-value assets at a near-zero attrition rate, while operating under the constraint of reduced operating budgets. Correspondingly, there may still exist the

need to project airpower from FOBs with like capabilities of a CONUS base, using minimal assets for setup and sustainment. All aerospace bases present significant defense challenges in terms of retention of operability owing to the lethality and nonlinear attributes of the battlespace in 2025.[8]

Predictions concerning the future battlefield suggest that a theater of operations could well constitute and encompass the globe owing to space-based and inter-continental, surface-based strategic platforms (weapons and sensors). Thus, the "idea of a close engagement . . . will fade" and "disengaged conflict, a war fought from a distance that proceeds without massing of troops and weapons"[9] may be possible in the future. There may be no front line, it may be difficult to have secrets and bases in CONUS and abroad may be equally lucrative and vulnerable targets.

Successful targeting of an aerospace base can be pictured as a long chain of events (see fig. 2-2).[10] Increasing the level of uncertainty or difficulty in completing the associated tasks of a given link in the chain correspondingly increases the probability of error and thereby decreases the potential for effective targeting. The potential adversaries of the US in 2025 could presumably still use this targeting methodology or a near-facsimile thereof but operate at a much faster tempo than currently possible. Essentially, anything that sits still longer than a few minutes in 2025 is a viable target,[11] but not necessarily one that is always targetable and destructible.

Given the worst-case assumptions of a FOB in a high-threat environment with high-value resources, a runway of fixed-dimensions, and a high-operational tempo, aerospace base requirements are distributed under the following four major categories: low-observable base, shielded base, self-healing base, and mobile base. Irrespective of the category, the overarching concern is focused on reducing the number of core entities and protecting those that remain.

Low-Observable Base

Presently, bases are very large and easily identifiable. Base structures are fixed and typically laid out in symmetrical patterns organized around runways of at least 7,500 feet in length. Most MOB structures are categorized as "soft" targets with little or no attempt to conceal their physical identity. All air bases have visible control towers, runway and taxi lights, large fuel storage tanks, and flight line lighting. Adversaries

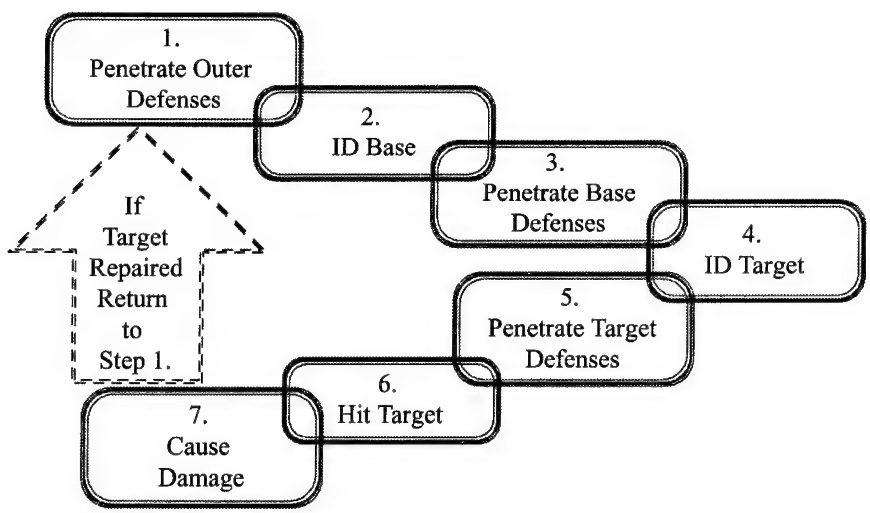

Figure 2-2. Targeting Chain of Events

can attack indirectly, using target coordinates, or directly, by target recognition, using any one of several spectral means. To survive and operate in 2025, aerospace base structures will have to be harder to discern and locate. Accomplishing this requires a combination of things to occur: (1) reduce the number of people and structures on-base, (2) increase the margin for error in threat system target acquisition, and (3) eliminate or "blend" all conspicuous aerospace base markings into the surrounding background. The concept is to stretch or completely break links two and four in the targeting chain of events previously denoted in figure 2-2.

Several technological advances need to be considered when developing this concept. Aircraft in 2025 could manifest dramatic improvements in reliability and maintainability when compared to their 1996 counterparts. It is feasible to expect a decreasing mean-time-between-failures rate.[12] Systems could be characterized by "graceful degradation"[13] with most hard failures requiring only the replacement of common circuit boards. Aircraft could be essentially self-contained for all normal operations and most maintenance operations.[14] The ramp population of aircraft ground equipment could be virtually nonexistent and what remains may only be used for abnormal equipment maintenance (engine removals). The explosive yield in conventional munitions could increase at least tenfold.[15] With added improvements in fusing and bomb case design, one or two bomb designs could conceivably replace today's myriad of cluster and conventional munitions, with a resultant smaller munitions storage area.[16] The improvements in systems reliability and munitions capabilities could reduce the number of people tied both directly and indirectly to the airfield. There may also be a resulting synergistic reduction in the number of storage buildings, houses, chow halls, and other facilities needed to be maintained in peacetime or protected in war, making the low-observable aerospace base less detectable.

Shielded Base

Should an attacker identify the location of an aerospace base, the next step in the successful attack chain is to prosecute an attack against the specific target(s). The adversary could threaten with a full range of attack methods—from sniping, to the use of precision guided munitions, to the use of a ballistic missile loaded with chemical or biological agents. Even directed energy attacks from space are plausible. The base commander will need a base that defends across the full attack spectrum if any modicum of operability is to be retained. The requirement then becomes to negate or interfere with the completion of steps three and five of the targeting chain of events denoted in figure 2-2. The aerospace base responds to the specific threat with a combination of autonomous and human-initiated self-protection mechanisms to defend itself.

A defense mechanism is any self-protective physiological reaction of an organism.[17] For an aerospace base, the self-protective reaction can be either to respond directly to defeat the threat or to mitigate the potential for damage. To actively respond to the threat, the base commander needs access to a nearly seamless defensive system with integrating intelligence and defense assets. The thrust is that no matter what the level of attack, the base commander will have a tiered defensive capability to prevent successful penetration of the aerospace base domain. Should the attacker penetrate the outer defensive tiers and successfully attack a structure or system, the aerospace base must be able to minimize the damage to the assets contained therein.

The aerospace base will also have to employ passive defensive techniques and technologies. This includes reducing the number of core entities, hardening the remaining structures, proliferating redundant

key operating systems, and using advanced camouflage, concealment, and deception techniques. Power sources must be efficient and robust, allowing for uninterrupted operation for extended periods. Facilities must have an independent power supply with a reduced spectral signature to prevent adversarial targeting.

Operational control of defensive systems by the base commander could be accomplished through enhanced situational awareness. Enhanced SA, as defined for the purpose of this paper, is the enabler which permits the "human-in-the-loop" to correlate, decipher, and react appropriately to various simultaneous aural, visual, and electronic sensor inputs with greater rapidity and assuredness. This means the commander will need full and unfettered access to all levels of information. Lastly, and to facilitate joint and combined operations, sensory and communication capabilities must be survivable, redundant, and interoperable with allied nations and sister services.

Self-Healing Base

The final option in breaking the targeting chain of events is to recover quickly from a successful attack. The desired result is to place the enemy back at step one in the attack chain, as depicted in figure 2-2. In 2025, seconds may be a decisive factor in deterring, defeating, or withstanding an attack. The aerospace base will have to recover quickly from any disruptive attack with minimal, if any, external support. Quick recovery first requires being able to recognize the extent of damage. Recovery may then take the form of repairing or replacing the structure or system or just absorbing the damage and operating with a minimal loss of capability. Today's air base uses huge stockpiles of material for postattack recovery—the aerospace base of 2025 should not.

Mobile Base

The need for forward presence will not be eliminated in 2025; however, the manner in which forward presence is executed is expected to change. Therefore, at a minimum, a very definite requirement could exist to provide a versatile and mobile force packaging capability in order to accommodate forward presence requirements. As it stands now, the ability to select FOB sites is severely constrained by several limiting factors—the need for a NATO standard runway, water, fuel, ammunition, people, and supplies are among the most prominent. The FOB represents the most difficult operating environment. To meet the challenge of the operating environment of 2025, FOBs have to become smaller, reaching the point where each can be deployed, set up, and sustained entirely by air. The goal is to be able to select an aerospace base location using only a cursory map survey and selecting map coordinates for precision siting.

Core Entity Migration

Table 1 depicts, arguably, the most important entities relevant to today's operability requirements and their current status as either core, intermediate, or peripheral entities. Additionally, the table depicts those same requirements and their envisioned status (core, intermediate, or peripheral) in 2025 with regard to meeting the aforementioned operability requirements.

The denotation of core, intermediate, and peripheral does not necessarily correlate to importance but more appropriately to the entity's survivability or replaceability. For example, runways today are extremely difficult to construct and repair. Because severe cratering degrades sortie generation, runways are designated a core entity and require a high-level of protection. In 2025, the requirement for a runway will exist, but due to technological applications, it should be easier to construct and repair. Runways should require a much lower-level of protection and contribute to the reduced

Table 1
Reducing Core Functions

Entity	Today		2025	
	MOB	FOB	MOB	FOB
Runway	Core	Core	Intermediate	Peripheral
Power	Core	Core	Intermediate	Peripheral
Fuel	Core	Core	Core	Core
Ordnance	Core	Core	Intermediate	Intermediate
Operators (Crews)	Core	Core	Core	Core
Maintainer/Acft	Core	Core	Intermediate	Intermediate
Airframes/manned	Core	Core	Core	Core
UAVs	Core	Core	Intermediate	Intermediate
Water	Core	Core	Core	Core
Civil Engineers	Intermediate	Core	Peripheral	Intermediate
Facilities	Intermediate	Intermediate	Intermediate	Peripheral
Security	Core	Core	Intermediate	Intermediate
Command, Control, Communications, Computers, and Intelligence (C^4I)	Core	Core	Peripheral	Peripheral

effectiveness of adversarial bombing due to their ease of repair. Conversely, aircrews of manned aircraft, a core entity today, could remain a core entity in 2025, largely due to the inability to quickly replace a trained aircrew.

As derived from table 1, the number of core entities in 2025 is significantly reduced from that of 1996. Core entities are reduced from 11 at a MOB and 12 at a FOB in 1996, to four for both the MOB and FOB in 2025. The accompanying net reduction in core entities provides a more equitable balance between the number of core entities and the defense required to protect them. Knowing the desired end-state, the task then devolves to defining those emerging technologies which could provide the means to achieve the desired balance between core entities and self-defense means of the mobile aerospace bastion.

Notes

1. Department of Defense (DOD), Joint Publication 1-02, *Dictionary of Military and Associated Terms*, 23 March 1994, 224.

2. Air Force Pamphlet (AFP) 93-12, *Contingency Response Procedures*, vol. 2, n.d., I-3.

3. DOD, Joint Publication 1-02, 154.

4. David A. Shlapak and Alan Vick, *Check Six Begins on the Ground: Responding to the Evolving Ground Threat to U.S. Air Force Bases*, RAND Report MR-606-AF (Santa Monica, Calif.: RAND, 1995), xv.

5. Ibid.

6. USAF Scientific Advisory Board, "New World Vistas: Air and Space Power for the 21st Century" (unpublished draft, the materials volume, 15 December 1995), 29.

7. *New World Vistas*, sumary volume, 32.

8. Evaluation Division, *Warfighting Vision 2010: A Framework for Change* (Fort Monroe, Va.: Joint Warfighting Center, 1 August 1995), 3, 5.

9. Gary Stix, "Fighting Future Wars," *Scientific American*, December 1995, 94.

10. The targeting chain of events is a team-derived construct developed to visualize and discuss the general events associated with target acquisition and desired effects.

11. Institute for National Strategic Studies, *Project **2025*** (Norfolk, Va.: National Defense University, 6 May 1992), 37.

12. Dr Craig M. Brandt et al., "Logistics ***2025***, Changing Environments, Technologies, and Processes" (Wright-Patterson AFB, Ohio: Graduate School of Logistics and Acquisition Management, Air Force Institute of Technology, n.d.), 27–28.

13. Adm William A. Owens, "A Report on the JROC and the Revolution in Military Affairs," *Marine Corps Gazette* 79, no. 8 (August 1995): 51.

14. Brandt et al., 27.

15. *New World Vistas*, summary volume, 9.

16. Ibid., 37.

17. *Webster's New World Dictionary of the American Language*, 2d ed., s.v. "defense mechanism."

Chapter 3

System Description

The first stage is the formulation of a felt want by the fighting Service. Once this is clearly defined in terms of simple reality it is nearly always possible for the scientific experts to find a solution.

—Winston Churchill

Integrated System

The aerospace base of 2025 is a dynamic and integrated system, providing warfighters with a seamless and robust base of operations. Gone are the stovepiped, manpower-intensive systems of 1996. They have been replaced with a ubiquitous architecture linking personnel, facilities, utilities, defense, and logistics into a seamless information net which is self-monitoring and accessible to all personnel, from headquarters to the lowest-ranking airman on the base.[1] The movement of core entities to the intermediate and peripheral categories (see table 1) through the application of technology has made them more survivable, more rapidly repairable, and so pervasive they are virtually indestructible. This then provides a survivable base to the warfighter, irrespective of the threat environment. Prolific ground sensor fields cover and surround the base providing complete situational awareness to command and defense personnel. Overhead, a fleet of unmanned aerial vehicles (UAV) provide additional sensor capability, exchange information with satellites, as well as function collaterally as standoff weapon platforms for base defense.[2]

Enumerated below are selected technologies and applications that, if developed, could facilitate the movement of aerospace base core entities to the intermediate and peripheral categories, reduce defensive requirements, increase survivability, and ultimately achieve the reality of an aerospace sanctuary. They offer but one possible combination for the attainment of the concept of operations delineated in this paper. (A more complete picture of aerospace base operations in 2025 follows in chapter 4, Concept of Operations.)

Advanced Sensors

Aerospace base operational and defensive requirements necessitate continuous, near-real-time sensor coverage. Diverse sensor capabilities increase accuracy and identification probabilities and correspondingly lowers false alarms and error rates. Additionally, they are pervasive, aboard UAVs, on satellite constellations, and on the ground.[3] These staring and scanning sensors could produce multispectral and synthetic aperture radar images and light detection and ranging returns that could have a resolution of a few centimeters.[4] The UAVs "[could] deploy low-altitude or ground-based chemical sensors for accurate discrimination of chemical and biological agents."[5] These same sensors could be remotely interrogated, allowing them to have reduced size, weight, power, and vulnerability.[6] Fusing the sensor-derived information into the overall aerospace base communications architecture could give the commander a real-time view of the security status of the aerospace base and the surrounding area of interest. Approaching threats could be identified quickly and accurately. Integrating sensor information into a standoff weapon system could permit accurate targeting at increased distances from the aerospace base, increasing security and in turn making adversarial targeting more difficult.[7]

Countermeasures

Presuming advanced sensor technology will be widespread, advances by the United States (US) may be negated unless the technology is more skillfully deployed and employed. Care should be taken to seriously consider nontraditional methods and means of deploying sensors in order to retain some level of superiority. Additionally and given a wide-spectrum of sensor capabilities, weather, electromagnetic pulse (EMP), or other interference may sufficiently degrade aspects of the capability and necessitate a return to visual observation means.

Robotics

Use of robotics can synergistically increase effectiveness by reducing manpower, infrastructure, and other support systems typically required for 24-hour operations on the flight line, in the bomb dump, and around the base. Today's robot is a mere infant compared to what may be available in 2025. The present advantages of implemented parallel processing in robots allow rudimentary cognitive skills.[8] When combined with the limited motor sensory skills available today, robotic structures are able to perform limited inspections on aircraft.[9] By 2025, robots could be designed as advanced "tools" with the capability to fully inspect, diagnose, and maintain aircraft, as well as most other base systems for day-to-day operations.[10] Robots could be expected to perform refueling operations, buildup, transport and loading of weapons, security functions, and even explosive ordnance disposal. The large computing capacity expected to be available in 2025 suggests that a single robot may be capable of alternating among the aforementioned tasks for every aircraft on the flight line, including those of our allies. Each robot could be engineered to be resistant to varying types of environmental extremes to retain its functionality; that is, ultraviolet rays, precipitation, cold and heat, EMP, and chemical/biological attacks.

Countermeasures

Although constructed to withstand EMP and other destructive measures, the possibility still exists for mechanical and/or software failure. Lack of on-scene personnel to effect repairs may well cause a significant drop in work productivity until restoration occurs, backup systems are activated or additional personnel arrive.

Nanotechnology

Nanotechnology is a process whereby matter can be constructed from the atomic level up. When fully deployed, nanotechnology may create a new "industrial revolution," for lack of a better descriptor. Current estimates project 20–30 years for this technology to mature.[11] Nanotechnology starts with atoms and uses molecular-sized machines to put them together in predetermined configurations. Maturation of this technology could mean thorough and inexpensive control of the structure of matter.[12] Nanotechnology infers materials and, thereby, structures can be manufactured to whatever specification is required—change colors, adapt to ambient temperatures, flex with stresses and strains, counter harmful vibrations or resonance, and even self-erect.

Nanotechnology also has important ramifications for aerospace defense in 2025. One of the earliest predicted applications of nanotechnology is in the area of sensors.[13] This technology could produce sensors which are extremely lightweight, energy efficient, and inexpensive to mass-produce. Efforts are under way to produce sensor capabilities that include chemical and virus detection.[14] Cheap, mass-produced, highly sensitive sensors could convey the capability to cover the base and perimeter area with very accurate sensing devices that require only small amounts of energy for functioning.[15] Adaptations of nanotechnology

can reasonably be extended to provide multispectral sensing such as heat, acoustic, optic, olfactory, and seismic capabilities that give a sensitized and near-real-time picture of the base and its surroundings. In the area of smell, sensors could be used to detect individual human pheromones for positive identification of personnel approaching the base. The sensor system could provide an accurate identification, friend, or foe (IFF) capability that could be deployed throughout the base proper, as well as outside the perimeter. The sensor system's multispectral capability may provide an all-weather, day/night operational capability, as well. Heat, acoustic, optic, and seismic inputs—fused with the other characteristics previously defined—may enable precise identification of what or who has penetrated the sensor area, thereby eliminating false alarms but, more importantly, enable the appropriately tailored security response.[16]

Microelectromechanical Systems (MEMS)

MEMS are the products of combining miniaturized mechanical and electronic components in sizes no larger than postage stamps.[17] MEMS could potentially afford increased capability, hence greater operability, while simultaneously reducing the volume required to deploy the specified capability.[18] For example, Westinghouse Science and Technology Center has reduced a 50-pound bench top spectrometer to the size of a calculator. Application of this type of technology could result in inexpensive nuclear, biological, and chemical contamination detection on the battlefield.[19] Small, mass-produced sensors may make biological and chemical detection affordable, easy to deploy, and difficult to counter.

Nanotechnology and MEMS could be merged for use in environmental cleanup, including cleanup after a biological or chemical attack.[20] Professors at the University of California at Berkeley are working on a chemical factory on a chip. When activated by an electrical charge, chemicals move down to a reaction chamber on the chip. Added heat assists the chemical reaction, and the resulting chemical is discharged.[21] The end-product could very well be an antidote to a toxic substance propagated by adversaries or a lethal or nonlethal chemical designed to control crowds or halt intruders.

Researchers at the Massachusetts Institute of Technology (MIT) have invented robots, similar to ants, that exhibit certain limited aspects of intelligence and differentiated specialization such as avoiding shadows and staying away from each other. They are cheap and easy to reprogram.[22] "Thirty-five years from now, analogous small, lethal, sensing, emitting, flying, crawling, exploding and thinking objects may make the battlefield highly lethal."[23] Exploiting this capability by incorporating "intelligence" and IFF within our sensors could provide a "smart" minefield that extends as far from the installation as deemed necessary. This smart minefield could be programmed to automatically react/self-detonate to certain stimuli or be programmed to report findings and be command-detonated remotely by security forces.

Additionally, MEMS can make a material into a smart system. Researchers are making great strides in the area of intelligent materials. It is possible to animate otherwise inert substances through the application of a variety of devices: actuators and motors that behave like muscles; sensors that serve as nerves and memory; and communications and computational networks that represent the brain and spinal column.[24] Basically, intelligent materials allow structures to adapt to their environment, understand what is happening to them (cognizant of external forces or stimuli), and even record and report what they experience.[25] Such materials are currently in use.[26] Additionally, this technology could enable self-erecting buildings which are environmentally adaptive and self-aware.

Countermeasures

Overwhelming the sensor field with massive inputs, masking odors, or severe weather conditions may adversely affect sensor capabilities. The requirement for near-perfect accuracy may permit spoofing. In smart materials, complete destruction could obviously render the self-report and reconstruction capability nonfunctional.

Artificial Intelligence/Neural Nets

The principal technologies required to enable smart sensor networks to provide fused, intelligent information to the decision makers and enhance their situational awareness are artificial intelligence and neural net technologies. To enhance situational awareness it is necessary to fuse ". . . multivariate data from multiple sources which in turn can be retrieved and processed as a single entity."[27] Artificial intelligence and neural networks integrate sensor signals from various parts of the electromagnetic spectrum simultaneously and recognize more sophisticated patterns.[28] Efforts at the Machine Learning and Inference Center at George Mason University in Fairfax, Virginia, in working with pattern recognition, using large relational databases, are progressing remarkably well.[29] Advances in this research area may allow the development of applications which identify threats by using machine-learning algorithms to find patterns and associate the discerned threat with the learned pattern. Additionally, while exploiting artificial intelligence, smart nodes may be able to collect information from sensors and perform a variety of functions, including analysis and redistribution of the information.[30] Organizing the processing systems for these sensors into distributed systems should produce a robust and more survivable system, with no obvious targetable strategic core.[31] Hierarchical architecture, signal processing, and action occurring several levels away from the central processor are areas being looked at for intelligent materials and may be the answer for the sensor fields.[32]

Countermeasures

Artificial intelligence has proved more elusive than originally thought. Programming even commonly understood concepts is extremely difficult. Deception ploys by an adversary may be so unique, so completely unanticipated, and not contained within the software capability that the system can be spoofed.

Defensive Weapons

Nonlethal capabilities include but are not limited to the following: acoustical weapons, chemical disablers, low-frequency electromagnetic wave generators, and supercaustics.[33] The focus of these types of weapons is to preclude or mitigate the loss of human life. They are appropriate for peacekeeping operations or civil unrest scenarios. Given the wide-range of possible scenarios from operations-other-than-war[34] to full-scale war, flexibility in weaponry employment is deemed an enhancement to overall capability.

The Air Force Scientific Advisory Board in *New World Vistas, Air and Space Power for the 21st Century:* Summary Volume, states that "speed-of-light weapons with the full-spectrum capability to deny, disrupt, degrade, and/or destroy will leap past and could eventually replace many traditional explosive-driven weapons and self-protection countermeasure systems."[35] They identify five innovative technologies for "energy-frugal, practical directed energy weapons" and recommend the Air Force pursue them. These technologies are large, lightweight optics; high-power microwave antennas using thin membrane fabrication; high-power short-wavelength solid-state lasers; high average power phase conjugation; new approaches to adaptive optics and phased arrays of diode lasers. Application of these technologies to base defense weaponry could significantly

increase options and improve capabilities to repel attacks in 2025.[36]

Additionally, use of a propagated microwave field could create a protective energy dome effect over the base. Functionally, this protective energy dome could detect incoming projectiles, convert their kinetic energy, and use the converted energy to repel the projectiles, including those as large as an aircraft or as small as a bullet. Counters to an adversary's use of microwave or laser weapons include the use of a pulsed plasma jet to ionize the air, which could effectively blunt the effectiveness of these types of offensive weapons.[37]

Countermeasures

Microwaves, lasers, and beam weapons, in general, require a robust power source. Unless significant advances are made in power generation and consumption, power remains a core entity, and if successfully damaged or destroyed, it could leave the base defenseless. Accordingly, defensive weapons must include a range of alternative power source derivatives to eliminate single-point failures.

Biotechnology

The threat of chemical and biological weapon usage has the decided potential to become increasingly widespread as more countries develop and acquire this capability.[38] Decontamination efforts will have to address reduced manpower, ease of handling/disposal, and cost considerations. Advances in biotechnology may permit the development of enzymes, MEMS, or a synthesis of the two technologies which could either neutralize the contaminant or absorb it. Additionally, advances in doexyribonucleic acid (DNA) modification could result in the development of DNA-altering substances that neutralize contaminants.[39]

A new generation of materials, most probably composites, designed after principles of hierarchical structures in nature (biomimicking), manufactured at least in part by incorporation of biological self-assembly principles and processes (bioduplication), may result in materials having the behavioral properties of biological systems: durability, flexibility, responsive to change, reactive to internal injury (self-repairing), and/or damage tolerant.[40] It may be possible to genetically produce organically similar substances whose rate and consistency of growth could be used to grow materials and structures. The underlying concept adapted from these cited technologies is to be able to rapidly construct rudimentary structures, such as tents and paved surfaces, and expediently repair minimally damaged facilities.

Countermeasures

DNA advances could allow the development of new, possibly more lethal, compounds. Developing antidotes or DNA restructuring to neutralize new agents will be critical but time dependent. Introduced mutations or weed killer-like substances could alter normal growth patterns. Hardiness and resistance to nefarious attempts to alter original designs will need to be bioengineered in the early developmental stages.

Super Quantum Interference Devices (SQUID)

If a human must remain in the loop (and the presumption is that one must), the human also must be enhanced to avert "mental paralysis" due to information saturation. Enhancements to increase the cognitive capacity of future warriors would presumably improve information assimilation, information correlation, and decision-making processes; that is, situational awareness. One means by which improvement in these processes could be achieved is via bioelectronic enabling technologies. Envisioned is the placement of an embedded microprocessor in the brain, which is designed to increase

the efficiency in the way information is received, stored, correlated, and retrieved.[41] A complementary feature of bioelectronic enhancement would be the ability to interface/communicate directly with an external computer system, thus mitigating or eliminating the necessity for physical or mechanical interfaces.[42] "Neurocompatible interface" efforts to date have affirmatively demonstrated the capability to produce an image directly in an individual's mind via surgically invasive methods. Alternatively, related research at the Media Laboratory of MIT is directed towards the development of a surgically noninvasive, "wearable computer" which maintains a continual communications interface with the human "host."[43] Irrespective of the method used to bioelectronically enhance a human, the resultant increase in mental agility and capacity—combined with the capability to interface directly with computers—could exponentially decrease the potential for confusion and disorientation in highly taxing and stressful situations.[44]

Countermeasures

Countermeasures are death or surgical removal of the embedded microprocessor or spoofing by insertion of disinformation. Implementation of this capability would require a change in US social values, as this form of human "adaptation" is not presently, nor universally acceptable.

Advanced Materials

A promising area of technology involves the development of advanced materials. Today's composites are substances made of fibers spun from carbon, glass, and other materials, which are then fused into a matrix of plastic, ceramic, or metal. Composites can provide the same structural strength as steel, but, at only one-fifth of the weight. Many believe costs may fall below that of steel as the demand increases over the next few years. Consequently, many future systems and structures could be constructed with composites because of the economical efficiencies gleaned from the weight versus performance ratios. The transportation, electronics, and medical industries are the major users of this technology today. The transportation industry uses composites in the manufacture of aircraft and automobiles. The electronics industry uses composites for the manufacture of components like resistors and insulators while the medical industry uses composites for prosthetics, including dental ware. The latter application is an area of particular interest and potential utility. Dentists apply an enamel-like substance that bonds with existing surfaces and becomes superhard when exposed to a certain wavelength of light. Expanding the application of this technology to wearing surfaces such as roads, building exteriors, and runways may be feasible, providing a capability to easily construct, resurface, or repair the particular worn surface. Should this technology become feasible, then the overarching requirement to defend these elements of the aerospace infrastructure at all costs against damage or destruction would be eliminated.[45]

Holography

Advances in holographic imaging, combined with infrared signature generators and radar reflectors, could give the base commander the ability to project false targets designed to deceive the adversary. This capability could allow the projection of false targets and signature modification of actual structures or could enable defenders to completely hide a structure. Holography is deception 2025 style, intended to prompt a potential adversary to question the effectiveness of his reconnaissance systems and ultimately designed to impede or negate his targeting ability.

Visualization of intelligence supporting three-dimensional analysis is a project aimed at assisting analysts in visualizing and manipulating complex, changing

three-dimensional intelligence data.[46] Technicians use a cylinder approximately one meter in diameter and one-half meter high in which they project a three-dimensional, transparent spinning ball to recreate a three-dimensional tactical scenario. This image can be viewed from any side. Applied to aerospace base defense, a three-dimensional view of the battlespace could be generated encompassing the base proper and as far outside the perimeter as the sensor field extends. With near-real-time refresh capability, the commander can have an "unobstructed" view of the battlespace from a secure location. Projecting this picture to remote locations via the fused command, control, communications, computers, and intelligence (C^4I) base architecture could give base defenders a three-dimensional depiction of their assigned sector. Should technological advances allow the projection of images without the use of a cylinder container, false images could be projected at will to various locations to deceive adversaries.

Countermeasures

Unless the hologram is used in conjunction with other spectral deception means, adversaries probing with broad spectrum systems could uncover the ruse, rendering this capability only useful against unsophisticated target acquisition systems.

Power

The technological focus is to reduce cost to generate, transmit, distribute, operate, and maintain power generation systems. There is a great deal of potential for improvement over today's power generating systems. Currently, the power industry offers evolutionary improvements: high reliability components; smaller, high efficiency motors; automatic diagnostic and control systems; and multifuel generating equipment, to name a few. While alternative power sources, such as biomass, solar with photovoltaic receptors, geothermal, and wind all show promise, all suffer from the in herent problems of relatively low efficiency (conversion from source to useful distributed power) and lack of storage. Many of these systems require highly visible production systems. However, one truly revoluntionary advance could change the entire concept of power generation—that technology is superconductivity.

Superconductivity is the ability to conduct electricity without resistance.[47] While application of this technology is not feasible outside of a carefully controlled laboratory environment, there has been recent progress achieving superconduction at higher temperatures.[48] Increased interest among the scientific community indicates that this capability has a reasonably good chance of coming to fruition. Assuming a breakthrough does take place, power generation equipment could be made considerably smaller; because it would no longer have to produce excessive amounts of energy to overcome the problem of line loss due to the heat associated with resistance encountered in existing conducting materials. The potential exists, with the advent of nanotechnology, to assist the process along by permitting a material that is superconductive to be built upward from the molecular level.

Achieving superefficient power usage could permit the use of marginalized power generation sources, such as solar or photovoltaic. This may then eliminate the requirement for certain electrical power grids. As such, each building could be equipped with its own combination of standard and independent power generation sources,[49] making power ubiquitous, easy to maintain, and pushing it from a core entity to a peripheral entity.

Table 2 summarizes the applicability of each technology to the aerospace base concepts postulated in this paper. There was no attempt to quantify the payoff for each technology, this is covered in chapter 5. This table identifies whether the technology was applicable to the concept.

Table 2
Applicability of Technologies to Concepts

Technology	Application to Concept			
	Low-Observable Base	**Shielded Base**	**Self-Healing Base**	**Mobile Base**
Advanced Sensors		Yes	Yes	Yes
Robotics	Yes		Yes	Yes
Nanotechnology		Yes		Yes
MEMS	Yes	Yes	Yes	Yes
AI/Neural Nets		Yes	Yes	Yes
Defensive Weapons		Yes		Yes
Biotechnology		Yes	Yes	Yes
SQUIDs		Yes		
Advanced Materials		Yes		Yes
Holography	Yes	Yes		
Power	Yes	Yes	Yes	Yes

As shown, the two most versatile technologies are MEMS and advanced power generation. As the final column portrays, most technologies applicable to meet the first three concepts are leveraged to provide mobility. The application of each technology is discussed in the Concept of Operations (chap. 4).

Finding and exploiting new technologies is only one-half of the equation. Employing the technologies in innovative combinations to create a synergistic effect is at least as important, and one way of staying ahead of adversaries in a world of proliferating, inexpensive technology. The following chapter paints such a picture—a fully integrated, technologically enhanced, aerospace base in 2025. Thus, having formulated what is wanted and defined those wants in terms of simple reality for the experts to solve, the remaining step is to articulate the concept of operations for the aerospace base integrated system.

Notes

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6. Ibid.

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9. Andrew Kupfer, "A Robot Inspector for Airplanes," *Fortune* 127, no. 9 (3 May 1993): 93.

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14. Langreth, "Molecular Marvels," 75.

15. USAF Scientific Advisory Board, "New World Vistas: Air and Space Power for the 21st Century" (unpublished draft, the sensors volume, 15 December 1995), 146.

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19. Ibid., 121.

20. Barbara Starr, "Super Sensors Will Eye the New Proliferation Frontier," *Jane's Defence Weekly* 21, no. 22 (4 June 1994): 92.

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22. INSS, 36.

23. Ibid.

24. Craig A. Rogers, "Intelligent Materials," *Scientific American* 273, no. 3 (September 1995): 122.

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26. "Smart Structures Dampen Motion, Increase Stability," *Signal* 8, no. 8 (April 1994): 20.

27. Department of the Air Force, *Spacecast 2020: Operational Analysis* (Maxwell AFB, Ala.: Air University Press, June 1994), 56.

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29. Peter Wayner, "Machine Learning Grows Up," *Byte*, August 1995, 63.

30. INSS, 39.

31. Ibid., 39.

32. Rogers, 125.

33. ***2025*** Concept, No. 90026, "Commander's Universal Battle Display," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

34. Department of Defense, Joint Publication 3-07, *Joint Doctrine for Military Operations Other than War*, 16 June 1995, I-1.

35. *New World Vistas*, summary volume, 60.

36. Ibid.

37. Mark Lehr, Phillips Lab, Kirtland AFB, N. Mex., telephone interview, February 1996. AFIT technologists and ***2025*** assessors expressed skepticism regarding the invulnerability of the energy dome, as well as the associated energy consumption requirements.

38. INSS, 45.

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41. ***2025*** Concept, No. 900523, "Chip in the Head," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

42. ***2025*** Concept, No. 900246, "The Borg," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

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45. "Advanced Composites," *Scientific American* 273, no. 3 (September 1995): 126–27.

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48. Ibid., 130.

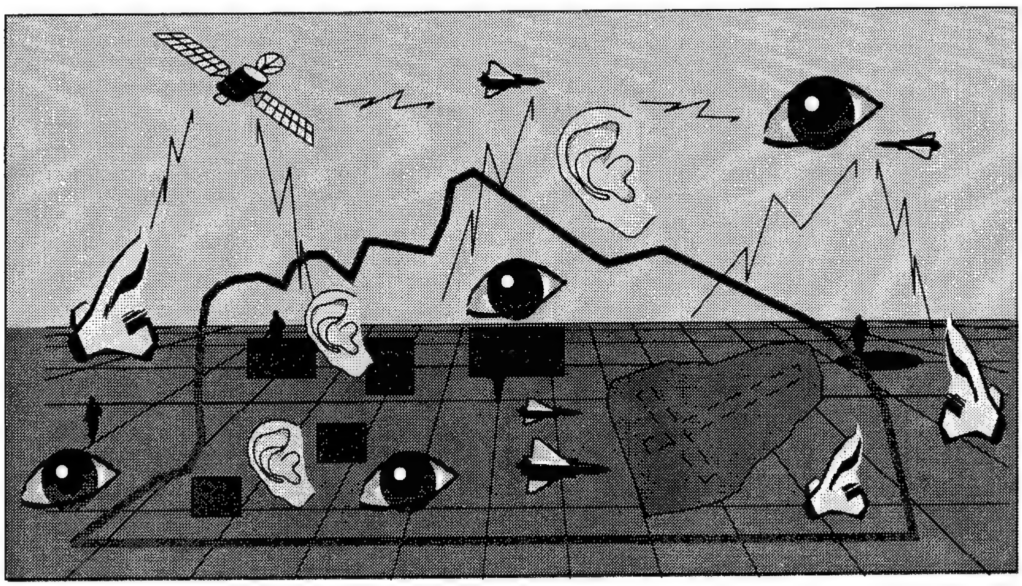
49. Independent power generating sources may include any combination of following: solar collectors, photovoltaic collectors, high-power lithium batteries, and standard electric power generators. The particular combinations will be highly dependent upon the required use, as well as, the geographic location.

Chapter 4

Concept of Operations

It is a doctrine of war not to assume the enemy will not come, but rather to rely on one's readiness to meet him; not to presume that he will not attack, but rather to make one's self invincible.

—Sun Tzu
The Art of War



Source: Microsoft Clipart Gallery © 1995 with courtesy from Microsoft Corp.

Figure 4-1. Concept of Operations Pictorial—2025

Introduction

The pictorial is a symbolic representation of the aerospace base of 2025. The eyes, ears, and noses represent the pervasiveness of the "all-knowing" sensing attributes of the aerospace base, fused with and augmented by varying types of airborne sensor platforms. The nondescript depiction of the aerospace base (runways, buildings, and so forth) represents its inherent capacity to blend into its surroundings, thus making it nearly undetectable to an adversary. Lastly, the facial silhouette overlying the aerospace base symbolically represents the shield which surrounds the base with its complementary active and passive self-defense capabilities. The ensuing chapter paints a word picture that makes the graphic more meaningful and illustrates the plausibility of the concept.

This concept of operations (CONOPS) provides a multifaceted approach to operability and defense circa 2025. It

includes five distinct capabilities which national decision makers can pursue based on international and domestic policies, military requirements, and economic capacity. The five capabilities are day-to-day operations, low-observable base, shielded base, self-healing base, and mobile base. Although the capabilities provide optimum operating conditions when employed together as an integrated system, any one or combination thereof will still improve operability and defense. Each of the following sections will present possible methods of applying the previously described emerging technologies to improve the ability to operate and defend bases in the future.

Day-to-Day Operations

Base operations in 2025 may occur in a manner radically changed from that of today. Overall base infrastructures may be smaller due to a reduction of services or functions currently provided at today's bases. The Department of Defense may no longer maintain base operating support (BOS) activities such as medical, financial, base maintenance, housing, and morale and welfare functions on federal installations. These services could migrate to the civilian sector and be subsumed by commercial interests in the adjacent civilian communities. However, many of the same functions required today to support aerospace activities may still be needed in 2025, the difference being the way they are accomplished. Technological advances in computers and information networks, robotics, highly reliable systems and components and vastly improved power sources may enable highly effective and efficient base operations.

The information available to all base personnel should be incredible. At the touch of a finger, future commanders could have immediate access to such information as aircraft and base status, mission scheduling, intelligence reports, and even the number of box lunches ready at the chow hall. In fact, anyone on base with a need to know could have that same information just as easily.

All of the systems on base, whether they be aircraft, environmental control, or sanitation, could be dramatically more reliable. This should permit a tremendous reduction in the size and scope of logistics and maintenance required to sustain base operations. Robots could be used extensively to replace humans in many of the repetitive, human-intensive functions on the flight line, at the munitions storage areas, and throughout the rest of the base.

In 2025, our main operations bases (MOB) should, by necessity, function at the same operating level regardless of the threat condition. During normal operations, a MOB may be a veritable beehive of activity—but not to the naked eye with all base entities functioning as one integrated system. Operability would be a function of synergistically interconnected intelligent systems. The aerospace base would operate largely "hands off." Base systems would monitor and report on themselves through an interconnected artificial intelligence or neural net architecture. The routine health and status of the base would be monitored, controlled, and operated by this extensive computer system. The system would have multiple nodes, each more than capable of assuming overall direction, coordination, or control should any of the other nodes be incapacitated. Personnel would only be required to respond to complete outages, major malfunctions, and life/safety concerns such as accidents, fires, or other disasters. Facility and infrastructure maintenance personnel would rarely interface with base systems at all except for annual maintenance requirements owing to an expected and dramatic increase in systems reliability and improved building materials.

Base facilities, to include airfields, would be retrofitted with or constructed from stronger, more durable, and damage-resistant materials or composites. Most buildings, particularly the critical ones,

would be capable of monitoring their own conditions. The placement of various types of sensors and intelligent materials would give new meaning to the term *building systems.* Routine facility condition inspections would be minimized to only those circumstances when the "facility" notifies the maintenance personnel of a condition warranting their attention.

Runways and other airfield pavements—all pavements for that matter—would be capped or constructed with extremely durable and minimal-to-no-maintenance type materials without any overt markings. The era of repainting, resurfacing, or replacing pavements every five to 10 years would be long gone.

Similarly, a combination of improved space-based global positioning capabilities that work with enhanced aircraft guidance systems would eliminate the need for ground-based visual approach and airfield lighting systems. In fact, control towers would be nothing more than distant memories of earlier aviation days.

The remaining airfield operations would be automated and fine tuned specifically to accommodate a combat turn type of ramp function. On approach, aircraft would automatically report their status to the base system through an unmanned control center. The control center would distribute the data throughout the base. The distributed information would include tasking specified support functions. For instance, fuels would know how much fuel is required. Munitions storage would know which armaments to select and transport to the aircraft for loading. Aircraft maintenance would know whether they need to respond to the aircraft to conduct system checkouts, repair, or replace components, and exactly what they need to bring with them. The base would be totally coordinated in supporting the aircraft's next mission. The aircraft would be directed to a specific location on the airfield where all support functions would automatically converge. The entire operation would be handled predominantly by robots. Delivery and loading of munitions, refueling, and final system checkout would all be automated. The only humans involved in the operation would be those necessary to perform high dexterity operations and to visually supervise the activities.

These "automatic" sortie generation and aircraft/base maintenance capabilities could improve efficiency and timeliness of support, as well as, reduce overall costs due to fewer required personnel. The key to the success of this type of operation is to limit the opportunities for outside interference or disruption from potential adversaries. One possible solution could come from technology, as it may provide the defensive capabilities to make the core entities less detectable.

Low-Observable Base

The threat posed to our bases is certain to include precision munitions and the use of space-based reconnaissance and surveillance systems by potential enemies. This threat capability may mandate the employment of enhanced defensive deception capabilities.

With the application of specific technologies, it could be considerably more difficult to identify the most critical base structures in 2025. All external structural surfaces ("skins") could be covered by a "cloaking" film or paint which would provide an active means of camouflaging buildings, runways, equipment, and so forth. These "skins" would be capable of "blending" into the surroundings in chameleon-like fashion.[1] This may include changing both color and temperature to negate electro-optical and infrared reconnaissance and targeting systems. At a minimum, any materials used to cover new facilities or recover existing facilities should be tinted to better match or blend in with the existing environs.

Projection of multispectral holograms could mimic real targets, confuse targeting systems, and foil attacks requiring visual

target acquisition. Radar reflection enhancement devices could modify the electromagnetic picture. Commanders may also have the option of effecting the weather to further hide the base from several sensor detection spectrums.[2] Essentially, buildings, runways, vehicles, or even people would become virtually invisible.[3] Weapons acquisition systems would then be unable to accurately discern desired targets or aim points with any reliable degree of certainty. Furthermore, future structures could be fully independent and redundant. However, hiding a base may not be sufficient to thwart attacks.

Shielded Base

Defense of the base, regardless of whether a MOB or forward operations base (FOB), may vary in degrees, but not capability. The base system could coordinate and assimilate a multitude of active and passive defensive systems scattered throughout and beyond the base boundaries. This defensive system may consist of varying types of sensors and weapons systems, all interconnected to enhance the commander's situational awareness and reaction capability.

Encompassing and controlling all of the defensive sensors, countermeasures, and intelligence-gathering systems is a redundant, dispersed, situational awareness system. This neural net type C^4I system could integrate the incoming information from all data sources, positively identify the threat, and automatically coordinate a response. This ability to rapidly and precisely discern what the threat is, and then recommend an appropriate response would be a significant attribute of the system. If the object is human, the system would be able to identify who it is by cross-checking the human pheromone database.[4] Additionally, the neural net system could have the ability to produce a near-real-time, three-dimensional or holographic sand table image.[5] Any individual with a receiver device could be able to receive the entire picture modified to their particular requirements. For example, if a view of avenues of approach without the trees or the buildings is desired, they are "deselected," enabling an unobstructed view.

The base and its surroundings could be seeded with multispectral sensors to detect both air and ground threats accurately and consistently, far enough from the base to allow engagement without degrading the mission. Airborne and ground-based sensors could be widely dispersed, redundant with overlapping coverage, and extremely difficult to counter. Because of the sensor systems redundancy, elimination of one or more sensors would not eliminate the entire detection capability. The system should be designed to degrade gracefully and have enough power to operate for sustained periods without maintenance. Collectively, the sensors should provide a "brilliant" grid for threat detection and identification[6] throughout the entire spectral range.[7] The ability to detect and combine a wide range of signals from acoustics and pheromones, to motion and infrared, should allow highly accurate threat identification.[8]

Simultaneously, an overhead fleet of stealthy, extremely high-endurance, solar-powered UAVs could be positioned to orbit the base for months at a time. This fleet could have the ability to detect both airborne and ground threats and relay their location to remotely controlled fire control units.[9] Deployed in great numbers, the UAVs could also have the capability of providing standoff weapon support to security forces and serve collaterally as communication relays. The UAVs could be capable of receiving and relaying information from other sensor platforms, such as satellites and Airborne Warning and Control System.

The holographic projection of security personnel to challenge unidentified intruders may permit resolution of a potential situation without an actual physical response. For instance, should an intruder not respond

to the holographic warning, the standoff weapons capability of the UAVs could be brought to bear without jeopardizing the safety of security personnel. If a physical response is required, security force personnel could respond in small, environmentally controlled, self-contained hovercraft equipped with a variety of nonlethal and lethal weapons.

Another advantage of the sensor field would be its capacity to detect nuclear, biological, and chemical agents and respond autonomously.[10] Positive detection could automatically launch a decontamination missile programmed to detonate at a required altitude or signal selected UAVs to respond with neutralizing systems. Such systems could employ cleanup bugs or bioengineered enzymes. Application of the neutralizers could be accomplished via aerosol dispersal in quantities sufficient enough to form a suppression "cloud or fog" over the affected area. As the suppression cloud falls, the bugs remove and/or the enzymes react with the contaminants in the air and on the ground, rendering the area clean without any harmful residue.[11] Structures, aircraft, vehicles, and the like could be treated with a catalytic/enzymatic decontaminating coating to neutralize contaminants not affected by the aerosol dispersed enzymes.[12]

Improved sensor capabilities could also benefit buildings, no longer remaining dormant targets for adversaries. The most critical buildings could be outfitted with a combination of sensor-activated, reactive armor systems and advanced lightweight hardening materials that would make them less vulnerable to many types of munitions.

A final measure of passive protection is to be an energy field, covering the base like a dome. The energy field could detect airborne threats attempting to penetrate it. As the airborne object "collides" with the energy field, the kinetic energy produced by the collision could be transmitted down to the energy field's source ground station. If the object is determined not to be friendly, the ground station could retransmit that energy, multiplied, back to the front of the object, effectively stopping or deflecting it, much like a force field.

Other active capabilities to defeat or deter a threat to the base could incorporate lethal and nonlethal systems. Beginning with the lethal variety, directed energy weapons (DEW) are requisites for base defense. The ability to neutralize or destroy fast-moving or hardened threat platforms mandates the need for a highly accurate and reliable weapons platform(s) with superior lethality—these systems should provide that capability. DEWs could be mounted on ground-based platforms; long-endurance, high-orbit UAVs; space-based killer satellites; or a combination thereof. Point target lasers with a rapid recycling rate to allow multiple missile engagement, coupled with directed energy weapons could comprise the principle means for close-in defense.[13] UAVs loaded with scatterable "intelligent" mines would be on-call for dispersal against ground attacks should the need arise.[14] Lastly, robotic "insects" could be released to swarm and defeat preprogrammed targets.[15]

While this interconnected and layered passive and active defensive system may provide as close to an impenetrable fortress as possible, there always remain the possibility of an opponent discovering a way to penetrate or defeat the systems. Therefore, a capability to recover after an attack must be considered.

Self-Healing Base

The ability to sustain damage and recover while continuing to operate could be crucial to base operations, particularly during war. In 2025, postattack damage recovery could be nearly automatic with the level of human involvement much reduced from what it is today. Postattack actions include airfield and facility bomb damage assessment (BDA), explosive ordnance reconnaissance (EOR) and disposal (EOD), rapid runway repair (RRR), decontamination (DECON),

and bomb damage repair (BDR). The difference between today and 2025 may be the nature of response and timeliness of recovery operations. There may no longer be the need to dispatch the hundreds of vulnerable civil engineering troops to recover the base.

Recovery typically begins with EOR and BDA. These tasks could be conducted in a number of ways, depending on the nature and extent of damage. Robotic sniffers and MEMS, working in concert with existing sensor systems, could locate and identify unexploded ordnance (UXO) and damage. UAVs equipped with very high resolution multispectral imaging devices could assist with BDA while combat engineering personnel oversee the entire process. Once initial reconnaissance is accomplished, recovery teams could begin preparations to conduct RRR and BDR activities. However, the risk to personnel and equipment from any UXOs must first be minimized. This EOD phase of recovery could be accomplished using MEMS to seek and destroy, robots to disarm and remove, and/or portable tower-mounted directed energy weapons to blast away individual UXOs or more densely covered areas, like bomblet or mine fields, that pose extreme hazards.

While chemical or biological agents may be neutralized as previously discussed, some personnel may still be required to operate temporarily in chemical/biological environments. When that is the case, personnel could don new chemical-resistant battle dress uniforms (BDU)[16] and vastly improved gas masks with improved filtration, comfort, and visibility. The commander may have the option of enhancing the local weather to minimize or negate the effectiveness of many chemical and biological agents. Once the level of risk to recovery teams is deemed acceptable, full-scale recovery and repair operations could commence.

RRR could be accomplished by small teams of personnel and robotics equipment. Equipment could be compact and versatile, very much like the "bobcat" tractors used around today's construction sites, only these may be remotely controlled or programmable. The teams could push eject (pavements and substrate material displaced due to bomb penetration and explosion) back into craters. Next, they could apply chemical compounds or bioengineer catalysts that would penetrate and harden the material pushed back into the crater. The third step would involve the placement of expanding and self-leveling foam which would harden sufficiently to preclude the need for crater hole compassion. Finally, the teams resurface the crater holes with a remotely controlled machine, not unlike the systems currently used to resurface ice skating rinks. The machine could place materials which can either harden rapidly on their own or use a chemical or light-induced hardener. Use of this type of machine could ensure rapid repairs within the required roughness criteria for the pavements effected. This capability may enable crater repairs to be conducted by one person with a couple of pieces of equipment—a significant improvement over the 25–30 men per crater and multiple pieces of large construction equipment required today.

At the same time, facility BDR could be under way. Small teams of personnel and equipment would perform necessary repairs. Critical facilities and systems would sense and report the extent of their damage. Based on the reported information, certain capabilities or functions could automatically transfer to other facilities or systems until repairs are completed. Repair teams could be automatically tasked by the base system to respond to damaged facilities and systems in accordance with preestablished priorities. However, in some cases, depending on the type and scope of the damage, some facilities would be able to repair themselves. Facilities and systems could self-repair using MEMS or other specially embedded capsules. Repair teams would respond to effect more involved

repairs. Robots could be capable of applying expanding and self-hardening foams to cracks, crevices, and holes in walls and roofs. Additionally, teams could employ organic materials that would grow rapidly once a catalyst is applied, or sheets of composite materials which could be cast in place on-site. Regardless of the damage (not withstanding complete and utter destruction), each structure, runway, taxiway, or system is easily and rapidly repaired or replaced with minimal, if any, significant effect on base operations.

Mobile Base

FOBs may be required to support operations throughout the contingency continuum which may include everything from peace operations and humanitarian/ disaster relief to major regional contingencies. Unfortunately, there may not always be access to suitable base facilities in the most desirable or optimal locations. What follows is a CONOPS, nicknamed "Harvest Geronimo," for rapid power projection in 2025—a capability to rapidly deploy necessary forces along with the ability to establish and easily sustain forward bases virtually anywhere we want them. In essence, it describes a mobile base system that is "light on its feet."

The nickname is a hold over from the 1980s line of United States Air Force transportable bare base support systems in the vein of Harvest Bare, Eagle, and Falcon. It recalls the nomadic tendencies of early Indian tribes that set up camps wherever it was most suitable to their needs. It also draws reference to the traditional cry of paratroopers, who yelled "Geronimo" upon aircraft exit during paradrop operations. Harvest Geronimo is a self-contained, completely airmobile, air-droppable, self-erecting base support system with relatively small mass to the resulting volume of utility and employment.

The employment of the mobile base would always involve the following four phases: deployment, force beddown, sustainment (which includes preattack preparations and postattack recovery operations), and redeployment.

Phase I—Deployment

It all starts with mobility. A significantly improved fleet of long-range, heavy-lift aircraft could enable this CONOPS. Potential locations could be derived from varying intelligence means with the selection of the most suitable land area determined from a more advanced version of photogrammetry—essentially, virtual surveying. Should airfield facilities (runways, taxiways, and parking aprons) be required, commanders would have the option of improving substandard airfields or creating new ones. For the purpose of illustrating potential capabilities, establishment of a new airfield on a barren piece of land will be described.

First, the selected location could be secured by a rapid deploying force of one or more unmanned combat UAVs or "StrikeStars"[17] and an air base defense team. Cargo UAVs precision air-drop or disperse the weapons and sensor systems previously discussed in the section entitled "shielded base." The air base defense team facilitate system setup and checkout. Once the desired location is secure, an airborne base establishment team proceeds to the site to create the required airfield.

The next step of the operation is accomplished largely via airborne platforms. A specially equipped aircraft begin operations by making a few overhead passes to spray a polymeric soil cement-type substance that penetrates and hardens the soil to bearing capacity strengths commensurate with 1,000 pounds per square inch concrete. The application does not have to follow an exact geometric pattern, although application must be relatively consistent. Subsequent passes involve the aircraft spraying self-leveling foam-like compounds to fill in grade inconsistencies. This achieves desired flatness criteria without earth-moving, "cut

and fill" operations. The foam would harden rapidly into an expansive crystalline type composite with adequate structural capacity. The final step would be to surface the airfield. Here, the aircraft sprays a self-leveling, polymeric composite material which reacts with certain light wavelengths to bond and harden, using an airborne laser system (ABL). The ABL scans the prepared surfaces at the desired wavelength and dwell time to complete the job. The landing surface is then ready for use, with one notable exception—it looks more like a "puddle" than a runway. Incidentally, parking aprons and taxiways are simply extensions to the puddle, constructed in the same fashion.

An alternative approach to airfield establishment may be the use of organically similar materials which apply the concepts of bioduplication or biomimicking to essentially grow airfield surfaces. The airfield surface structural sub-bases would be established in much the same way as with the preceding method. In this case, materials would be placed in desired areas and treated with catalysts or reagents that would spur rapid growth and hardness. Once again, the airfield would not take the standard geometric shapes of today. An added advantage of organic airfields, from a camouflage, concealment, and deception (CCD) standpoint, would be their similarity to the surrounding environment.

Phase II—Force Beddown

This phase begins with precision guided airdrops, thereby avoiding the need for large-scale, cargo-handling operations on the ground. Facilities, equipment, and personnel would be precision air-dropped into the cantonment area or "point-of-use."[18] Upon contact with the ground, troops depart their air-dropped personnel carriers and facilitate base setup and system checkout. The air-dropped facilities then self-erect. Deployed personnel create a 2025 version of tent city, albeit far smaller than what is currently required. To accomplish this task, personnel would use rapid biological growth kits which involve the erection of lightweight skeletal structures to serve as growth frameworks. Troops would then simply apply, most likely by spraying, organic materials, and catalysts to "grow" the facilities. The resulting facility would take the requisite shape by following the previously erected structure and provide a shelter no less stable (perhaps more so) than the tents used today. Other facilities self-erect by mechanical processes or inflation. Such facilities could be used to shelter the more critical functions and systems.

The power infrastructure would consist of extremely efficient sources that will be simple to set up and maintain. Advances in superconduction to enable near-zero resistance at ambient temperatures may enable the installation of small distributed and networked power generation systems requiring less fuel as a result of their ability to transmit electricity without having to overcome excess requirements due to line losses. Some of the smaller sized units may use an alternative fuel, such as nitrogen (an extremely prevalent and inexpensive fuel source) for power conversion. Even batteries could have far greater life spans and approach the capability of miniature power plants.

All ground-based command, control, communications, computers, and intelligence (C^4I) will be small, extremely powerful systems that take advantage of the same superconductive materials and computer advances discussed in previous sections. Some C^4I systems may be in the form of manpacks, used by security and other operations personnel, differing only in the quality and quantity of information available to the users. The entire system would be fused to ensure complete and near-real-time situational awareness.

Phase III—Sustainment

The sustainment phase of operations would be essentially the same as at a main operations base (MOB) and perhaps even

less manpower intensive. It would involve standard base operations as well as preattack and postattack activities.

Standard base operations would be a function of logistics. Logistical systems would be minimal and most likely just-in-time. Resupply could be accomplished via airdrop. High reliability and low maintenance systems lead to very few support personnel and a reduced logistics tail. Further, the probability of extending the mean-time-between-maintenance for up to 60 days will make logistics simple and manageable. Munitions and fuel could remain as the only continuing logistical concern. However, efficiency of delivery and loading operations on the ground could be enhanced greatly by all-terrain versions of the robotic systems employed at MOBs.

Preparation for attack would actually be coincidental to the initial turn-on of base functions. As much as possible, hardening, CCD techniques, and systems would be designed into the self-erecting structures and deployed systems. Many aspects, like false signal emitters, would simply be unleashed. Much like the concept of the "low-observable base," the FOB would become an extremely difficult target to acquire and damage.

Since there are no guarantees against successful attacks, forces must be prepared and capable of recovering damaged facilities and airfields. The same systems employed at the MOB would be suitable for FOBs. However, repair may actually be more a function of replacement due to existing expedient construction techniques and airlift improvements. Operations would continue to follow these general processes until the mission is complete.

Phase IV—Redeployment

The final aspect of mobility operations is redeployment. Only the high-tech, smart facilities (self-erecting) would be repackaged for shipment back home. Many, if not most of these items, could be aerially extracted via a fleet of UAVs. Depending on the location of the FOB, the UAVs could either deliver the items to a staging base or directly back to the point of origin. The organic facilities, including the airfield surfaces, could be disposed of in-place. They could be sprayed with biodegradable enzymes or other corrosive substances to effectively disintegrate right where they were initially emplaced. This capability could negate the use of such facilities and/or locations by potential adversaries. Redeployment would be as efficient and expedient as deployment, and all systems immediately available for reuse at another location, should it be required.

Conclusion

These capabilities could enhance the ability to project power, regardless of location, by essentially creating a sanctuary from which the US, and her allies, may pursue national objectives. The real challenge is in determining investment paths and priorities. Acquisition of these capabilities may not be cheap, but the derived benefits most certainly outweigh the associated costs.

Notes

1. ***2025*** Concept, No. 900605, "Active Cloaking Film/Paint," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

2. Lt Col Brad Shields et al., "Weather as a Force Multiplier: Owning the Weather in ***2025***," (Unpublished white paper, Air Command and Staff College, n.d.).

3. ***2025*** Concept, No. 900573, "Dielectric Materials for Stealth," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

4. ***2025*** Concept, No. 900567, "If I Can Smell You . . . ," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

5. ***2025*** Concept, No. 900206, "Commander's Universal [Order of] Battle Display," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

6. ***2025*** Concept, No. 900368, "Land Identification, Friend or Foe," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

7. ***2025*** Concept, No. 900508, "Magnetic Detection of Aircraft," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

8. ***2025*** Concept, No. 900518, "Electronic Grid Throwaway Sensors," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

9. ***2025*** Concept, No. 900953, "Multi-Sensor, High Altitude, Long Endurance UAV," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

10. Chemical and biological agents will be candidates for cleanup by advanced enzymes or catalysts; but, radiation hazards will still require time to decompose in accordance with their respective half-life.

11. ***2025*** Concept, No. 900388, "Smart Bugs," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

12. Larry M. Sturdivan et al., "Chemical and Biological Defense for the New Century," *Army Research Development and Acquisition*, July–August 1995, 28.

13. ***2025*** Concept, No. 200009, "Pyrotechnic Electromagnetic Pulse," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

14. ***2025*** Concept, No. 900350, "Aerial Mines," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

15. ***2025*** Concept, No. 900612, "Bumble Bee Bombs," ***2025*** Concepts Database (Maxwell AFB, Ala.: Air War College/***2025***, 1996).

16. Sturdivan et al., 27–28.

17. Lt Col Bruce W. Carmichael et al., "StrikeStar ***2025***" (Unpublished white paper, Air Command and Staff College, n.d.).

18. USAF Scientific Advisory Board, *New World Vistas: Air and Space Power for the 21st Century*, summary volume (Washington, D.C.: USAF Scientific Advisory Board, 15 December 1995), 31–32.

Chapter 5

Investigation Recommendations

We should base our security upon military formations which make maximum use of science and technology in order to minimize numbers of men.

—Dwight D. Eisenhower

No single technology or system will bring the operability and defense concepts to fruition. In and of itself, the 2025 aerospace base is an integrated system dependent upon advances in a number of fields and disciplines. A subjective rating system was developed in an attempt to rank the technologies introduced in chapter 3. This limited evaluation provided a single-weighted score for use in comparing all of the technologies against each other based on a set of qualities defined by the research team.[1] Each team member ranked the qualities from one to eight (eight = most important) to derive an average quality weighting factor. Table 3 shows final average ranking for the qualities used to rate the technologies. The top three are *enhance operability*, *enhance survivability*, and *cost-effectiveness*.

Each member then rated individual technologies against the quality criteria as defined below. The scores were summed up and multiplied by the weighting factor to arrive at a final weighted score. The qualities used to score the technologies follows.

Enhance Operability

Will the technology enhance aerospace base operability as defined in chapter 1? Sample attributes to consider include technology effects on sortie generation rate, base systems reliability, manning levels, and sustainment needs. Scale is from one to five (five = revolutionary enhancement; 3 = significant enhancement; 1 = modest enhancement).

Enhance Mobility

Will the technology enhance aerospace base mobility? Factors include enhancements to airlift deployment requirements, ease of setup for forward deployed bases, and redeployability. Scale is from one to five (five = revolutionary enhancement; three = significant enhancement; one = modest enhancement).

Table 3
Average Quality Ranking Matrix

	Enhance Operability	Enhance Mobility	Enhance Survival	Enhance Recovery	Cost-Effective	Feasible	Commercial Application	Other Military Applications
Total Ranking Scores	36	19	31	14	26	18	18	17
Average Quality Ranking	7	4	6	3	5	4	4	3
								Maximum Possible Ranking = 8

Enhance Survivability

Will the technology enhance aerospace base survivability from all levels of attack? Attributes to consider include ability to prevent or minimize damage from the full spectrum of attacks, ability to degrade gracefully, and ability to improve base self-defense effectiveness. Scale is from one to five (five = revolutionary enhancement; three = significant enhancement; one = modest enhancement).

Enhance Recoverability

Will the technology enhance aerospace base recoverability after an attack? Attributes include minimizing downtime after attack, ability to reopen runways, and ability to clean up unexploded ordnance and residual contaminants. Scale is from one to five (five = revolutionary enhancement; three = significant enhancement; one = modest enhancement).

Cost-Effectiveness

To what extent does the technology improve aerospace base operability and defense compared to the cost of implementation by the military? This is the most subjective of the quality measurements. A high score implies a high benefit to cost ratio. This can be the case either because the military absorbs the full cost and gets a tremendous return, or the commercial sector pays for the development and the military only pays for conversion. Scale is from one to seven (seven = significantly cost-effective; five = moderately cost-effective; three = neutrally cost-effective; one = not cost-effective).

Feasibility

What is the probability that technology will advance enough in key areas to provide the capability described in the concept by 2025? Scale is from one to five (five = very high feasibility; three = moderate feasibility; one = low feasibility).

Commercial Applications

To what extent does the concept have technology spin-offs which have application within the commercial sector? A high score implies that there could be significant cost savings in the development or production costs due to commercial interest. Scale is from one to five (five = extensive commercial applications; three = moderate commercial applications; one = minimal applications).

Military Applications

To what extent does the technology have other military applications? A high score implies that development costs will be leveraged across numerous military development programs. Scale is one to five (five = significant number of other military applications; three = moderate amount of other military applications; one = minimal amount of other military applications).

Results

Table 4 shows the average ratings for each of the technologies. The maximum possible total score for any technology is 25. The last column shows the total score for each technology as a percentage of the maximum possible score. These percentages are also shown graphically on figure 5-1.

As the data shows, most of the technologies are grouped within a 12 percent band. Only three technologies, SQUIDs, holography, and directed energy weapons seem to drop out of contention. The top two technologies, superconductivity, and MEMS, standout from the rest of the group while alternate power sources and artificial intelligence/neural nets round out the top four.

Although the results are limited by their subjective derivation, they indicate a distinct predilection for technologies that directly improve operability and indirectly improve base defense and correspondingly reduce the core entity ring. Two of the top four technologies are related to revolutionizing the way base systems

Table 4
Average Technology Ratings Matrix

	Enhance Operability	Enhance Mobility	Enhance Survival	Enhance Recovery	Cost-Effective	Feasible	Commercial Application	Other Military Application	Total Weighted Score	% Maximum Score
Super-conductivity	4.8	4.4	3.4	2.6	3.9	3.0	5.0	4.8	19.1	76%
MEMS	4.2	4.0	4.2	4.0	3.1	4.0	4.6	4.0	18.8	75%
Alternate Power Sources	4.2	4.2	4.2	3.0	2.6	3.6	4.8	4.2	18.0	72%
AI/Neural Nets	4.2	2.4	4.0	3.0	3.3	4.0	4.6	4.2	17.7	71%
Advanced Materials	3.8	4.4	3.8	3.0	2.6	4.2	4.2	4.4	17.5	70%
Nano-technology	3.8	4.0	4.0	3.6	2.7	3.0	4.4	4.0	17.2	69%
Robotics	3.8	2.8	2.8	3.6	2.9	4.4	4.4	4.2	16.5	66%
Biotechnology	3.4	3.2	3.8	4.2	2.9	3.4	3.6	3.6	16.3	65%
Advanced Sensor Fields	3.2	2.0	4.4	2.6	3.3	4.0	3.2	4.0	16.1	64%
Defensive Weapons	2.6	2.0	4.4	2.4	3.1	4.2	1.4	4.6	14.9	60%
Holography	2.6	2.0	4.0	1.8	1.9	3.8	3.2	3.4	13.3	53%
SQUIDs	3.2	1.6	2.8	2.0	2.0	2.0	1.4	4.0	11.6	46%

Maximum Possible Ranking = 25

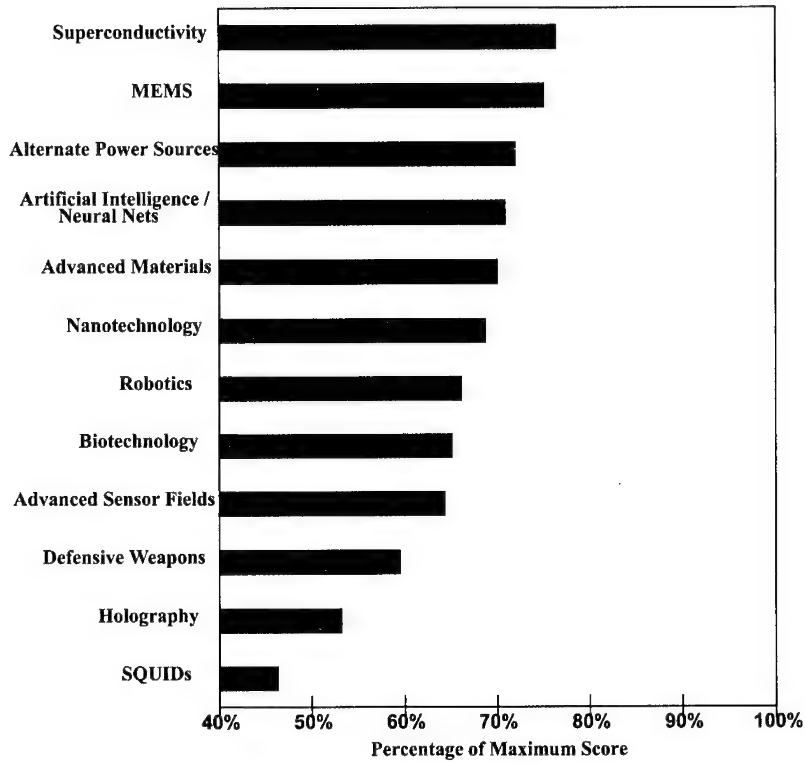


Figure 5-1. Average Technology Rating—Graphic Depiction

generate power, taking power generation from a key core entity to the intermediate or peripheral entity category—these are synergistic technologies. As ambient temperature superconductivity becomes possible, the use of alternate power generation methods becomes more cost- and performance effective. The broad applications of MEMS for use in low-observable facilities, battle damage repair, and self-erecting structures have the potential to also move several additional entities out of the core entity category. Finally, artificial intelligence offers the potential to provide the synergism needed at the base level to integrate and operate all of these capabilities. The low scores for directed energy weapons, holography, and SQUIDs are a reflection of their applicability to only the defense side of operability and defense.

The capabilities envisioned for the aerospace base of 2025 could become available incrementally with a combination of commercial and government investment in diverse technologies. For many of these technologies the driving factor will be the development costs. Figure 5-2 shows an estimate of the relative development cost sharing for each technology area discussed above.[2]

On a positive note, the top technologies recommended by the research team have significant commercial applications and investment potential which may be readily leveraged by the military. Some of the cited technologies are further from reality than others; however, the facilities they would effect are being built today. Consideration on how to effect the transition which will enable the application and use of these new capabilities is strongly recommended. As an example, we spend a great deal of money and effort improving the human factors of base systems and aircraft maintenance. Consideration should begin with regard to

making systems suitable for robots—robonomic.[3] New construction and facilities modifications should, at a minimum, consider the need for future low-observable retrofits and modifications for hardening or use of reactive armor. Ongoing environmental cleanup and the increasing threat of biological and chemical contamination strongly suggests a continuing need to consider the means to take advantage of biotechnology for contaminant cleanup.

None of the technologies and concepts discussed above is singularly important to operability and defense. Together though, they provide a quantum synergism that can greatly increase the effectiveness and survivability of the 2025 aerospace base. In the year 2025, operability and defense will not and cannot be mutually exclusive. Day-to-day operations will have to consider the potential for instantaneous transitions to combat footing. This applies to CONUS-based MOBs and FOBs. Reducing the number of core entities provides an obvious improvement in base defense since the number of entities that have to be protected "at all costs" goes down. There is a corresponding, though less obvious, improvement in day-to-day base operability. The steps taken to reduce core entities include improvements in base systems reliability, decreases in base manning levels, and use of reliable, low-cost power generation, among other things. All are steps which combine to simplify day-to-day operations and even reduce the operating costs. The upshot is that most of the technologies identified in this research paper have civilian applications or military applications in other areas. The downside is that today's base infrastructure is typically tomorrow's infrastructure, so implementation of these concepts will need to start today.

Summation

The issue of operability and defense in the year 2025, and as presented in this paper, is not one based exclusively on arguments for the development or advancement of a specific technology or technologies. Nor is the issue of operability

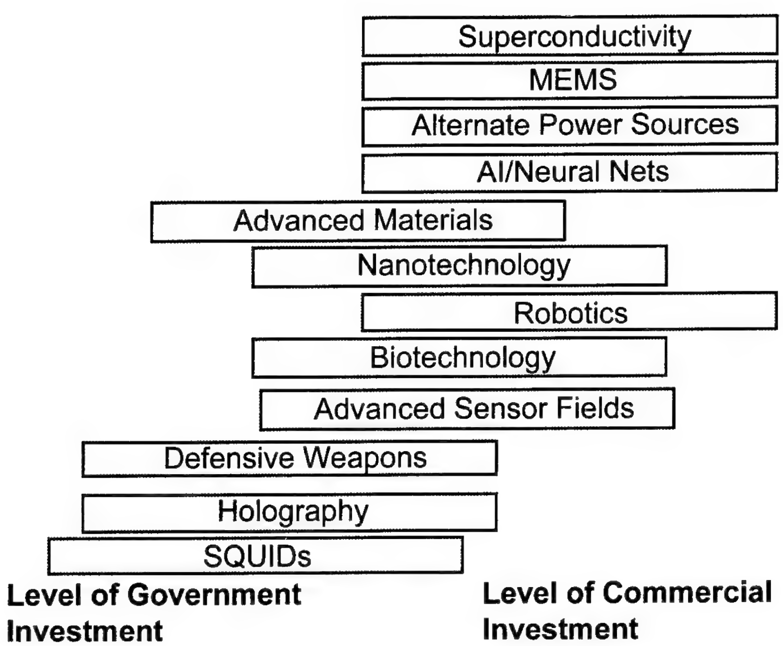


Figure 5-2. Development Cost Sharing

and defense focused narrowly on developing a singular system which will permit the aerospace base of 2025 to function and sustain aerospace power projection, despite actual or attempted disruptions. The integrated system inherent to the aerospace base of 2025 denotes a major revolution in operability and defense because of its force enhancement qualities of adaptability, defensibility, mobility, reliability, and survivability. Within this construct, vulnerabilities of the integrated system resident at an aerospace base have not been discounted but considered in terms of their elimination. Successful attacks on the whole or parts of the system, by a determined adversary, have not been discounted either but addressed in terms of building in robustness and redundancy, allowing for graceful degradation.[4] Reduction of the number of core entities, so vital to the functioning of the aerospace base, has been presented as a viable means to preserve the functionality of the base to support its designated mission.

So it is, that the five force enhancement qualities of adaptability, flexibility, mobility, reliability, and survivability are integrated throughout the aerospace base infrastructure. In the end, the overarching vision for the integrated aerospace base of 2025 is not derived from the objective of developing an impregnable fortress. The vision articulated in this paper is focused on providing a sanctuary for aerospace dominance through the creation of a low-observable, shielded, self-healing, and mobile aerospace base. This vision includes reducing and dispersing core functions, thereby reducing the consequences of attack. Finally, by using new technologies to accomplish this, and by creating a sanctuary, the aerospace base becomes a source of energy and replenishment that enhances aerospace power.

Notes

1. The evaluation qualities can be viewed as two categories; functional qualities related to how well the technology enhances aerospace base operability and defense, and implementation qualities which provide insight into the likelihood of the technology being affordable or doable. However, all eight qualities were ranked as one group since any future development program will have to trade off cost, performance, and schedule qualities as necessary to decide which technologies to pursue.

2. This is a subjective assessment derived from each team member's impressions of each of the technologies researched. As such, the assessment only provides a very rough idea of the split between government and commercial funding for development. Thus, subsequent investigation should refine and validate these findings.

3. Term contrived by the team to denote ergonomic considerations for robots.

4. Adm William A. Owens, "A Report on the JROC and the Revolution in Military Affairs," *Marine Corps Gazette* 79, no. 8 (August 1995): 51.

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